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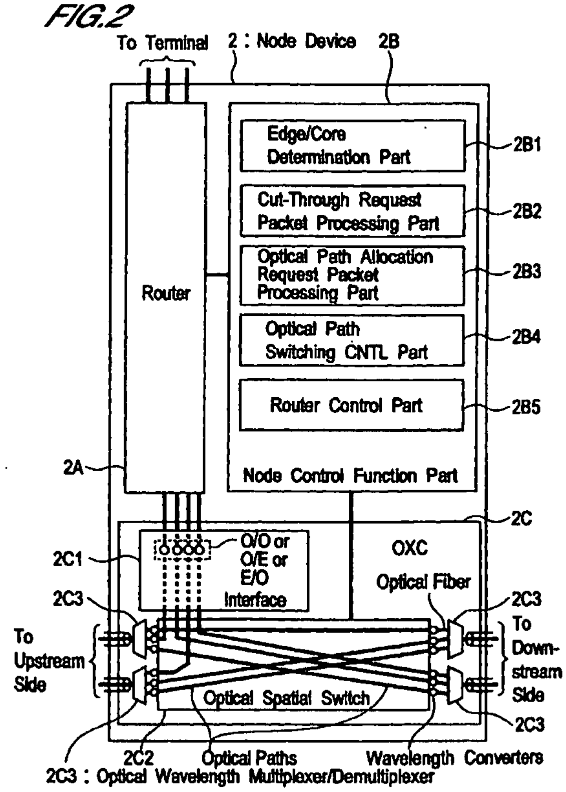
(54) Node control device, node device and optical path setting method

(57) A method for setting a cut-through optical path in an optical network system (Fig. 3, Fig. 4, Fig. 6, Fig. 8 and Fig. 9) is proposed. At first, a destination side edge node device (2R) which confirmed the transfer of a packet to a terminal accommodated by the present node device (2) or to an access system network notifies the open resource information of the present node device to a transmission side edge node device (2S). Then the transmission side edge node device determines the optimum allocation of an optical path to be set on the transfer route based on the open resource information notified by the destination side edge node device and a core node device (2M1, 2M2). Then, according to the allocation of the optical path determined in the previous step, the transmission side edge node device, the core node device, and the destination side edge node device set the optical path which omits the packet transfer processing (layer 2 and layer 3 processing) in transit nodes.

FIG.2



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a node control device, node device and optical path setting method suitable for establishing an optical network system.

Description of Related Art

[0002] Fig. 1 shows an aspect of a conventional optical network system. As Fig. 1 shows, the optical network system comprises user terminals 110 connected to routers (or a packet switching machine) 100 and optical cross-connects or optical add-drop-multiplexer (OADM) 130 which are connected with the router 100 and are inter-connected via inter-office optical fibers 120. The optical cross-connect 130 is an device for executing the relay/insertion (add) /extraction (drop) of optical signals and the setting connection of optical signals (that is, optical paths 140) between two node devices which are not necessarily adjacent to each other.

[0003] Some of the optical cross-connects 130 do not use wavelength division multiplexing transmission technology, but they also handle optical paths which are optical signal connections given by OCDM or OTDM technology. The many optical cross-connects use a wavelength division multiplexing transmission technology where a plurality of optical signals are sent over one optical fiber, and these multiplexed signals are used as a resource for transmission so as to increase capacity. Actually, the optical cross-connects 130 in Fig. 1 can multiplex a plurality of optical signals having different wavelengths using wavelength multiplexers/demultiplexers and optical spatial switches. An interface 150 is disposed between the router 100 or electronic switching machine (for example, SDH systems or ATM systems) and the optical cross-connect 130 shown in Fig. 1. For this interface 150, wavelength variable (or fix) type O/O (optical/optical) or E/O (Electric/Optical) conversion device and O/E (Optical/Electric) conversion device are used.

[0004] Next a packet transmission aspect implemented on such an optical network system will be explained. At first, a packet sent from a user terminal 110 is transmitted to the router 100 via the transmission path. The router 100 analyzes the header of this packet, and transfers the packet to an input interface 150 of the optical path (connection of optical signals) 140 which is set between routers (strictly speaking, an optical path is allocated between interfaces for routers in different nodes) where the destination terminal is connected to or an appropriate router for relaying. By repeating such an operation (packet relay by routers), the transfer target packet reaches the router 100 accommodating the destination user terminal, and is transferred to the destination user terminal 110 via this router.

[0005] The optical path 140 shown in Fig. 1 is set by the optical cross-connect (e.g. optical ADM (Add/Drop Multiplexer)) 130 and the optical fiber 120. The input/output interface 150 is disposed between the optical cross-connect 130 and the packet switching machine (e.g. router, electronic switching machine) 100.

[0006] Setting of the optical path 140 in the above mentioned optical network system, however, is semi-fixed. So a method for dynamically setting this optical path 140 according to the traffic is under current study.

[0007] It is accordingly the first object of the present invention to provide an optical path setting method for dynamically setting an optical path according to the traffic.

[0008] It is a second object of the present invention to provide a node control device for such an optical path setting.

[0009] It is the third object of the present invention to provide a node device having such a node control device.

SUMMARY OF THE INVENTION

[0010]

(A) To achieve these objects, the first configuration example of the node control device of the present invention is a node control device which is disposed in each node device constituting an optical network system, and is used for controlling the packet transfer operation in each node device, comprising:

(1) edge/core determination means for determining whether a node device which the node control device is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device, a core node device, or a destination side edge node device for the transfer packet to be processed;

(2) cut-through request packet processing means which, when the present node device is the destination side edge node device, notifies the open resource information of the present node device to the upstream side of the transfer route as a cut-through request packet, and, when the present node device is the core node device, transfers the cut-through request packet after adding thereto the open resource information of the present node device which is received from the downstream side of the transfer route or is individually generated;

(3) optical path allocation request packet processing means for determining an optimum allocation of an optical path based on the open resource information of the cut-through request packet transferred to the transmission side edge node device, and notifying the allocation

to the target transmission side edge node device, core node device, and destination side edge node device respectively by an optical path allocation request packet, and

(4) optical path switching control means for controlling an optical switch according to the allocation notified by the optical path allocation request packet, setting an optical path which omits the layer 2 and layer 3 processing, and notifying the completion thereof to the transmission side edge node device by an optical path setting completion notice packet.

By the present invention, the optical path is set with the packet flow as a trigger, then packets go through the set optical path so that the device load on layer 2 and/or layer 3, such as a router of the core node device, can be decreased.

With this configuration according to the present invention, an optimum optical path allocation can be determined by the transmission edge node device, so applying an excessive load on the destination side edge node device can be prevented.

(B) The second configuration example of the node control device of the present invention is a node control device which is disposed in each node device constituting an optical network system, and is used for controlling the packet transfer operation in each node device, comprising:

(1) edge/core determination means for determining whether a node device which the node control device is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device, a core node device, or a destination side edge node device for the transfer packet to be processed;

(2) cut-through request packet processing means which, when the present node device is the transmission side edge node device, notifies the open resource information of the present node device to the downstream side of the transfer route as a cut-through request packet, and, when the present node device is the core node device, transfers cut-through request packet after adding thereto the open resource information of the present node device which is received from the upstream side of the transfer route or is individually generated;

(3) optical path allocation request packet processing means for determining an optimum allocation of the optical path based on the open resource information of the cut-through request packet transferred to the destination side edge node device, and notifying the allocation to the target transmission side edge node device, core node device, and destination side edge node device respectively by an optical path allocation request packet; and

(4) optical path switching control means for controlling an optical switch according to the allocation notified by the optical path allocation request packet, setting an optical path which omits the layer 2 and layer 3 processing, and notifying the completion thereof to the transmission side edge node device by an optical path setting completion notice packet.

By the present invention, the optical path is set with the packet flow as a trigger, then packets go through the set optical path so that the device load on layer 2 and/or layer 3, such as a router of the core node device, can be decreased.

With this configuration according to the present invention, an optimum optical path allocation can be determined by the destination side edge node device, which allows to prevent an excessive load from being applied on the transmission side edge node device.

(C) The third configuration example of the node control device of the present invention is a node control device which is disposed in each node device constituting an optical network system, and is used for controlling the packet transfer operation in each node device, comprising:

(1) edge/core determination means for determining whether a node device which the node control device is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device, a core node device, or a destination side edge node device for the transfer packet to be processed;

(2) cut-through setting packet processing means which, when the present node device is the destination side edge node device, notifies the open resource information of the present node device to the upstream side of the transfer route as a cut through setting packet, and, when the present node device is the core node device, determines whether cut through by the open resource indicated in the cut-through setting packet received from the downstream side of the transfer route is possible, and if possible, transfers the received cut-through setting packet to the upstream side of the transfer route after adding the information to the cut-through setting packet, and if impossible, transfers the received cut-through setting packet to the upstream side of the transfer route after adding thereto the cut-through information which has been set thus far and the open resource information of the present node

device; and

(3) optical path switching control means which, when the cut-through setting packet processing means determines that cut through is possible, controls an optical switch so as to set an optical path to the resource for which it was determined that cut through is possible.

With this configuration according to the present invention, the possibility of setting of a cut-through optical path is autonomously determined during the process for transferring the open resource information of each node device from the destination side edge node device to the transmission side edge node device, and the optical path is set when setting is possible, so the required time until setting can be decreased.

(D) The fourth configuration example of the node control device of the present invention is a node control device which is disposed in each node device constituting an optical network system, and is used for controlling the packet transfer operation in each node device, comprising:

(1) edge/core determination means for determining whether a node device which the node control device is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device, a core node device, or a destination side edge node device for the transfer packet to be processed;

(2) cut-through setting packet processing means which, when the present node device is the transmission side edge node device, notifies the open resource information of the present node device to the downstream side of the transfer route as a cut-through setting packet, and, when the present node device is the core node device, determines whether cut through by the open resource indicated in the cut-through setting packet received from the downstream side of the transfer route is possible, and if possible, transfers the received cut-through setting packet to the downstream side of the transfer routeafter adding the information to the cut-through setting packet, and if impossible, transfers the received cut-through setting packet to the downstream side of the transfer route after adding thereto the cut-through information which has been set thus far and the open resource information of the present node device; and

(3) optical path switching control means which, when the cut-through setting packet processing means determines that cut through is possible, controls an optical switch so as to set the optical path to the resource for which it was determined that cut through is possible.

With this configuration according to the present invention, the possibility of setting a cut-through optical path is autonomously determined during the process for transferring the open resource information of each node device from the transmission side edge node device to the destination side edge node device, and the optical path is set when setting is possible, so the required time until setting can be decreased.

(E) According to the fifth configuration example of the node control device, it is preferable that each of the first to fourth configuration examples of the present invention further comprises forced releasing means for forcibly releasing the optical path when a predetermined time has elapsed since setting of the optical path, or when a decrease in the number of communication packets is confirmed at the node device positioned at both ends of the optical path. This function allows prevent an unnecessary waste of resources.

(F) According to the sixth configuration example of the node control device, it is preferable that each of the first to fifth configuration examples of the present invention further comprises cut-through optical path necessary/unnecessary determination means for determining the necessity of cut through before transmitting the cut-through request packet or transmitting the cut-through setting packet, so that the cut-through optical path is selectively set only when determined as necessary. This function allows to prevent the setting of the cut-through optical path for a small volume of packets, so as not to waste resources.

(G) According to the seventh configuration example of the node control device, it is preferable that each of the first to sixth configuration examples of the present invention further comprises information channel insuring means for determining whether the information channel is continuously insured after setting the cut-through optical path between the node devices on the route where the cut-through optical path is set before transmitting the cut-through request packet or transmitting the cut-through setting packet, and setting the cut-through optical path only when the information channel is insured.

With this configuration according to the present invention, the cut-through optical path is set only when the information channel is insured, so a state where information cannot be forwarded between the node devices on the optical path route after setting the cut-through optical path can be absolutely prevented.

(H) According to the first configuration example of the node device of the present invention, a node

device comprises:

(1) a router for determining the output destination of a transfer packet which is input according to the header information of the layer 3;
(2) an optical cross-connect for extracting (dropping) optical signals from an optical fiber or inserting (adding) optical signals into an optical fiber, or relaying optical signals between arbitrary input/output optical fibers for optical path setting; and
(3) anode control device according to one of the above mentioned first to seventh configuration examples for switching a connected pair of each input port and output port inside the optical cross-connect according to the instructions of the received transfer packet or based on self judgment.

By using such a configuration of the node device, the node device of the present invention can implement such effects as optimizing the cut-through optical path, decreasing the cut-through optical path setting time, effective use of resources and insuring the information channel.

(I) According to the second configuration example of the node device of the present invention, it is preferable that the first configuration example of the node device further comprises a switch which connects a destination-based buffer to some of the outputs from the router to the optical cross-connect, and can connect a packet read from the destination-based buffer to an arbitrary input port of the optical cross-connect. This configuration allows to improve band-width efficiency using the cut-through optical path.

(J) According to the third configuration example of the node device of the present invention, it is preferable that the above mentioned second configuration example of the node device further comprises allowable delay recognition function means at the router for determining the allowable delay of a transfer packet, so that only packets with a large allowable delay are allowed to be output to the destination-based buffer and packets with a small allowable delay are directly output to the optical cross-connect. This configuration allows to avoid a state where a packet with a small allowable delay time, such as a real-time type packet, is stored in the destination-based buffer, and the deterioration of communication quality can be effectively prevented.

(K) According to the fourth configuration example of the node device of the present invention, a node device comprises:

(1) a router for determining the output destination of a transfer packet which is input according to the header information of the layer 3 (=IP layer);
(2) an optical cross-connect for extracting (dropping) optical signals from an optical fiber, or inserting (adding) optical signals into an optical fiber, or relaying optical signals between arbitrary input/output optical fibers for optical path setting;
(3) a node control device according to one of the above mentioned first to sixth configuration examples for switching a connected pair of each input port and output port inside the optical cross-connect according to instructions of the received transfer packet or based on self judgment; and
(4) optical path extraction/insertion (drop/add) means for the information channel for extracting (dropping) optical signals (destination side optical path termination) with a fixed-wavelength insured for the information channel from the optical fiber, or for inserting (adding) the optical signals (source side optical path termination) with a fixed wavelength into the optical fiber, so as to enable communication of information signals with another node device.

By using such a configuration for the node device, the node device of the present invention can not only implement such effects as optimizing the cut-through optical path, decreasing the cut-through optical path setting time and effective use of resources, but also insure the information channel.

(L) According to the fifth configuration example of the node device of the present invention, a node device comprises:

(1) a router for determining the output destination of a transfer packet which is input according to the header information of the higher layer (= IP layer);
(2) an optical cross-connect for extracting (dropping) optical signals from an optical fiber, or inserting (adding) optical signals into an optical fiber, or relaying optical signals between arbitrary input/output optical fibers for optical path setting;
(3) anode control device according to one of the above mentioned first to sixth configuration examples for switching a connected pair of each input port and output port inside the optical cross-connect according to the instructions of the received transfer packet or based on self judgment; and
(4) pilot tone signal transmission means for the information channel for overlaying pilot tone

signals for the information channel on the optical path for user data or separating pilot tone signals for the information channel from the optical path for user data so as to enable communication of information signals with another node device.

By using such a configuration for the node device, the node device of the present invention can not only implement such effects as optimizing the cut-through optical path, decreasing the cut-through optical path setting time, and effective use of resources, but also insure the information channel.

(M) According to the sixth configuration example of the node device of the present invention, it is preferable that, in the above mentioned fifth configuration example of the node device, the pilot tone signals for the information channel are transmitted by a time division multiplex system, so that the potential collision of pilot tones can be eliminated.

(N) According to the optical network system of the present invention, an optical network system is constituted by providing a plurality of node device according to one of the above mentioned first to sixth configuration examples of the node device, so that the optical network system can implement such effects as optimizing the cut-through optical path, decreasing the cut-through optical path setting time, effective use of resources, and insuring the information channel.

(O) According to the first configuration example of the optical path setting method of the present invention, an optical path setting method in an optical network system comprises:

(1) a step where a destination side edge node device which confirmed the transfer of a packet to a terminal accommodated by the present node device or an access system network notifies the open resource information of the present node device to a transmission side edge node device;

(2) a step where the transmission side edge node device determines an optimum allocation of an optical path to be set on the transfer route based on the open resource information notified by the destination side edge node device and the core node device; and

(3) a step where the transmission side edge node device, the core node device and the destination side edge node device set the optical path which omits the packet transfer processing (layer 2 and layer 3 processing) in transit nodes for the optical path determined in the previous step.

This can provide an optical path setting method which can prevent applying an excessive load on the destination side edge node device.

(P) According to the second configuration example of the optical path setting method of the present invention, an optical path setting method in an optical network system comprises:

(1) a step where a transmission side edge node device which confirmed the transfer of a packet to a destination notifies the open resource information of the present node device to a destination side edge node device;

(2) a step where the destination side edge node device determines the optimum allocation of the optical path to be set on the transfer route based on the open resource information notified by the transmission side edge node device and the core node device; and

(3) a step where the transmission side edge node device, the core node device and the destination side edge node device set the optical path which omits the packet transfer processing (layer 2 and layer 3 processing) in transit nodes for the optical path determined in the previous step.

This can provide an optical path setting method which can prevent applying an excessive load on the transmission side edge node device.

(Q) According to the third configuration example of the optical path setting method of the present invention, an optical path setting method in an optical network system comprises:

(1) a step where a destination side edge node device which confirmed the transfer of a packet to a terminal accommodated by the present node device or to the access system network transmits the open resource information of the present node device to a transmission side edge node device which is at the upstream side; and

(2) a step where the core node device and a transmission side edge node device, to which the open resource information is transferred, determine respectively whether the setting of a cut-through optical path is possible based on the open resource information received from the downstream side of the present node device, and if possible, the core node device and the transmission side edge node device set a cut-through optical packet using the resource which was determined as possible, and notify the information to the upstream side, and if impossible, the core node device and the

transmission side edge node device add the cut-through information which has been set thus far and the open resource information of the present node device to the received open resource information, and transfer it to the upstream side.

With this configuration according to the present invention, the possibility of setting a cut-through optical path can be autonomously determined during the process where the open resource information of each node device is transferred from the destination side edge node device to the transmission side edge node device, and the optical path is set if setting is possible, so the required time until setting can be decreased.

(R) According to the fourth configuration example of the optical path setting method of the present invention, an optical path setting method in an optical network system comprises:

(1) a step where a transmission side edge node device which confirmed the transfer of a packet to a destination transmits the open resource information of the present node device to a transmission side edge node device which is at the downstream side; and

(2) a step where a core node device and the destination side edge node device to which the open resource information is transferred determine respectively whether the setting of a cut-through optical path is possible based on the open resource information received from the upstream side of the present node device, and if possible, the core node device and the destination side edge node device set the cut-through optical packet using the resource which was determined as possible, and notify the information to the downstream side, and if impossible, the core node device and the destination side edge node device add the cut-through information which has been set thus far and the open resource information of the present node device to the received open resource information, and transfer it to the downstream side.

With this configuration according to the present invention, the possibility of setting a cut-through optical path can be autonomously judged during the process where the open resource information of each node device is transferred from the transmission side edge node device to the destination side edge node device, and the optical path is set if setting is possible, therefore the required time until setting can be decreased.

(S) According to the fifth configuration example of the optical path setting method of the present invention, it is preferable that, in the optical path setting method according to the above mentioned first to fourth configuration examples, the optical path is forcibly released when a predetermined time has elapsed since the setting of the optical path or when a decrease in the number of communication packets is confirmed at the node device positioned at both ends of the optical path.

(T) According to the sixth configuration example of the optical path setting method of the present invention, it is preferable that, in the optical path setting method according to the first to fifth configuration examples, the necessity of cut through is determined before setting the cut-through optical path, and the setting processing is continued only when the necessity is determined. This function allows to prevent setting the cut-through optical path for transmitting just a small volume of packets for example, so resources are not wasted.

(U) According to the seventh configuration example of the optical path setting method of the present invention, it is preferable that, in the optical path setting method according to the above mentioned first to sixth configuration examples, it is determined whether the information channel is continuously insured after setting the cut-through optical path between the node devices on the route where the cut-through optical path is set before setting the cut-through optical path, and the cut-through optical path is set only when the information channel is insured. In this way, according to the present invention, the cut-through optical path is set only when the information channel is insured, and thereby a state where information cannot be forwarded between the node devices on the cut-through optical path route after setting the cut-through path can be absolutely prevented.

(V) According to the eighth configuration example of the optical path setting method of the present invention, it is preferable that, in the optical path setting method according to the above mentioned first to seventh configuration examples, a packet read from the destination-based buffer is transmitted to the cut-through optical path after setting. Thereby, band-width efficiency using the cut-through optical path can be improved.

(W) According to the ninth configuration example of the optical path setting method of the present invention, it is preferable that, in the above mentioned optical path setting method, only packets with a large allowable delay are stored in the destination-based buffer. This allows to prevent a state where a packet with a small allowable delay time, such as a real-time type packet, is erroneously stored in the destination-based buffer, and the deterioration of communication quality can be effectively

prevented.

(X) According to the tenth configuration example of the optical path setting method of the present invention, it is preferable that, in the optical path setting method according to the above mentioned first to sixth configuration examples and the eighth and ninth configuration examples, the information communication between the node devices, where the cut-through optical path is set, is implemented using optical signals with a fixed wavelength insured for the information channel after the cut-through optical path is set. This allows to always insure the information channel after the cut-through optical path is set.

(Y) According to the eleventh configuration example of the optical path setting method of the present invention, it is preferable that, in the optical path setting method according to the above mentioned first to sixth configuration examples and the eighth to tenth configuration examples of the above mentioned optical path setting method, the pilot tone signal for the information channel is overlaid on the optical path for user data to implement information communication between the node devices, where the cut-through optical path is set, after the cut-through optical path is set. This also allows to always insure the information channel after the cut-through optical path is set.

(Z) According to the twelfth configuration example of the optical path setting method of the present invention, it is preferable that, in the optical path setting method according to the above mentioned eleventh configuration example, the pilot tone signals for the information channel are transmitted in the time division multiplex system. This allows to eliminate the potential collision of pilot tones.

[0011] With the above mentioned configuration examples, each node device has an optical cross-connect as one composing element. However, each node device may use ADM (Add/Drop Multiplexer) having a switching function to switch the Add/Drop state/relay state instead of using the optical cross-connect.

[0012] According to a preferable example of an optical network system of the present invention, the system comprises a plurality of edge node devices which are designed as dedicated for respective edge nodes and one or more core node devices which are connected between said plurality of edge node devices via a transfer route and are designed as dedicated for respective core nodes. The edge node device is connected only between an external terminal, etc. and the core node device. The core node device is connected only with both or one of said edge node device and another core node device, and has core node input/output ports for forwarding a transfer packet with the other core node device but does not have input/output ports for forwarding a transfer packet with an external terminal.

[0013] With this configuration according to the present invention, it is preferable, in terms of construction cost, to provide an optical network system by providing a node device where the edge node device and core node device are designated as dedicated for the respective edge node and core node.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The foregoing and other objects, features and advantages of the present invention will be better understood from the following description taken in connection with accompanying drawings, in which:

Fig. 1 is a drawing depicting a prior art of an optical network system;

Fig. 2 is a functional block diagram depicting a first embodiment of the node device in accordance with the present invention;

Fig. 3 is a drawing depicting an embodiment of the optical network system in accordance with the present invention;

Fig. 4 is a drawing depicting a transfer path of packets in accordance with the present invention (first embodiment);

Fig. 5 is a functional block diagram depicting a second embodiment of the node device in accordance with the present invention;

Fig. 6 is a drawing depicting a transfer path of packets in accordance with the present invention (second embodiment);

Fig. 7 is a functional block diagram depicting a third embodiment of the node device in accordance with the present invention;

Fig. 8 is a drawing depicting a transfer path of packets in accordance with the present invention (third embodiment);

Fig. 9 is a drawing depicting another example of a transfer path of packets in accordance with the present invention (third embodiment);

Fig. 10 is a functional block diagram depicting a fourth embodiment of the node device in accordance with the present invention;

Fig. 11 is a functional block diagram depicting a fifth embodiment of the node device in accordance with the present invention;

Fig. 12 is a functional block diagram depicting a sixth embodiment of the node device in accordance with the present invention;

Fig. 13 is a functional block diagram depicting a seventh embodiment of the node device in accordance with the present invention;

Fig. 14 is a functional block diagram depicting an eighth embodiment of the node device in accordance with the present invention;

Fig. 15 is a functional block diagram depicting a ninth embodiment of the node device in accordance with the present invention;

Fig. 16 is a functional block diagram depicting a tenth embodiment of the node device in accordance with the present invention;

Fig. 17 is a drawing depicting an example of overlaying pilot tone signals in accordance with the tenth embodiment of the present invention;

Fig. 18 is a drawing depicting an example of a net where an optical network system is comprised of dedicated node devices;

Fig. 19 shows a configuration example of an edge node device dedicated to an edge; and

Fig. 20 shows a configuration example of another edge node device dedicated to an edge.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(A) Configuration of Optical Network System

[0015] Fig. 3 shows an embodiment of the optical network system in accordance with the present invention. As Fig. 3 shows, this optical network system comprises node device 2 to which one or more terminals 1 are connected, and optical fibers 3 which inter-connect these node device 2. Although Fig. 3 shows the case when the optical network is created in a net configuration, the optical network can also be created in a loop or other configuration.

[0016] In this optical network system, the node device in accordance with embodiments to be discussed later are used for the node device 2. In other words, the node device 2 comprises three functional parts: a router 2A, a node control function part 2B for controlling the operation of the node device in general, and an optical cross-connect 2C.

[0017] The optical cross-connect may include a wavelength converter and ADM (Add/Drop Multiplexer) having a switching function to switch the Add/Drop state/relay state may be used instead of the optical cross-connect. This means of implementing the optical switch is not restricted by a switch using the Opt-Electric effect, but a mechanical optical switch or a pseudo-optical switch having the same interface function, such as switching light to electricity by an electrical switch then converting it to light again, may be used.

[0018] These three functional parts need not be disposed in a single housing, but may be disposed in separate housings respectively. In the following description, an device which implements the optical path setting function, which is implemented by linking these three functional parts, is called the "node device".

[0019] In the following description, when it is necessary to distinguish the node device having a configuration unique to the present invention from an ordinary node device which is generally used, the node device having the configuration unique to the present invention is called the "IP (Internet Protocol)/optical multi-layer switch node device".

[0020] Now various embodiments will be described in sequence, taking an example in which the node device, node control device and the optical path setting method in accordance with the present invention are implemented as an IP/optical multi-layer switch node.

(B) First Embodiment

(B-1) Functional Configuration

[0021] Fig. 2 shows a functional configuration of the node device in accordance with the first embodiment. As Fig. 2 shows, or as the above description explains, the node device 2 comprises a router 2A, a node control function part 2B and an optical cross-connect 2C which is called as an optical XC. The node control function part is also referred to as node control device.

[0022] The router 2A has a function to read the header part from the packet signal which was input, and determines the output destination according to the destination described in this header part. The destination here is not only another node device or a terminal or access system network connected to the concerned node device (hereafter this may be referred to as "present node device"), but may be the present node device itself. The router 2A also has a function to notify the information on the transferred packet to the node control function part 2B.

[0023] The node control function part 2B has a function to switch the directions of the optical cross-connect 2C autonomously by the determination of itself or based on the instructions of the received packet. This node control function part 2B constitutes the major part of the node device in accordance with the present invention.

[0024] The optical cross-connect 2C has a function to channel optical signals input from another node device to an arbitrary output optical fiber by inserting (adding) the optical signals into the optical fiber net (i.e. source side optical path termination) or extracting (dropping) the optical signals from the optical fiber net (i.e. destination side optical path termination), so as to set an optical path between two node device which are physically not necessarily adjacent to each other.

(B-2) Configuration of Node Control Function Part 2B

[0025] The node control function part 2B in accordance with this embodiment comprises the following five functional parts.

(a) Edge/core determination part 2B1
(b) Cut-through request packet processing part 2B2
(c) Optical path allocation request packet processing part 2B3
(d) Optical path switching control part 2B4
(e) Router control part 2B5

(B-2-1) Edge/Core Determination Part 2B1

[0026] The edge/core determination part 2B1 is a function part for each node device to determine its position in the optical network system. The edge/core determination part 2B1 specifically determines whether the concerned node device, that is, the present node device is a transmission side edge node device, a core node device, or a destination side edge node device. This distinction is determined by the relationship between the present node device, that is, the IP/optical multi-layer switch node device, and a packet to be input to this node device. In the present invention, when the present node device is the IP/optical multi-layer switch node device, the transmission side edge node device, core node device and destination side edge node device are defined as follows.

Transmission Side Edge Node Device:

[0027] If a transfer packet is input to the present node device and the input origination node device of the packet is not IP/optical multi-layer switch node device of the present invention, then the present node device is the transmission side edge node device for the packet.

[0028] However, if a previous node device, to which a packet is input, of a node device is an IP/optical multi-layer switch, the management or operation thereof is executed by another network, and the optical path is always set with the present node device as the start point, then the present node device is the destination side edge node device.

Core Node Device:

[0029] If a transfer packet is input to the present node device and both the input origination node device of the packet and the destination node device to which the packet is transferred next are the IP/optical multi-layer switch node device of the present invention, then the present node device is the core node device for the packet.

Destination Side Edge Node Device:

[0030] If a transfer packet is input to the present node device and the destination node device to which the packet is transferred next is not the IP/optical multi-layer switch node device, then the present node device is the destination side edge node device for the packet.

[0031] However, it the next node device, to which the packet is transferred, of a node device is an IP/optical multi-layer switch, the management or operation thereof is executed by another network, and the optical path is always terminated by the present node device, then the present node device is the destination side edge node device.

[0032] In this way, the relationship between the present node device and the packet to be input thereto determines whether the IP/optical multi-layer switch node device of the present invention is the transmission side edge node device, core node device or destination side edge node device. Therefore, it is possible that an IP/optical multi-layer switch node device is defined as the transmission side edge node device based on the relationship with a packet, and is also defined as the core node device based on the relationship with another packet.

[0033] The edge/core determination part 2B1 determines which node device is the concerned node device, that is, the present node device, based on the above criterion.

(B-2-2) Cut-through Request Packet Processing Part 2B2

[0034] The cut-through request packet processing part 2B2 is a functional part for collecting optical path resource and trafic information required for setting a cut-through optical path. This functional part operates as follows according to the determination result of the above mentioned edge/core determination part 2B1.

[0035] If the present node device is determined as the destination side edge node device, then the cut-through request packet processing part 2B2 notifies the existence of the packet which passed through the present node device and the open resource and traffic information (e.g. wavelength) of the present node device as a cut-through request packet, to the node device which is positioned next to the present node device at the upstream side (transmission origination side).

[0036] If reception of the cut-through request packet is confirmed and the present node device is determined as the core node device for this packet by the edge/core determination part 2B1, then the cut-through request packet processing part 2B2 adds the open resource information of the present node device to the received cut-through request packet and transfers the packet to the node device at the upstream side.

(B-2-3) Optical Path Allocation Request Packet Processing Part 2B3

[0037] The optical path allocation request packet processing part 2B3 is a functional part for determining the allocation of a cut-through optical path based on the collected open resource information and requesting the setting of the cut-through optical path based on this allocation. This functional part operates as follows according to the determination result of the above mentioned edge/core determination part 2B1.

[0038] When the reception of a cut-through request packet is confirmed and the edge/core determination part 2B1 determines that the present node device is the transmission side edge node device for this packet, the

optical path allocation request packet processing part 2B3 calculates the optimum allocation of the optical path based on the open resource information and other data like traffic information included in the packet. Or the processing part 2B3 determines the optimum allocation of the optical path based on the lock-up table, instead of the above calculation. The processing part 2B3 notifies the cut-through optical path setting request based on the result to the present node device, the core node device and the destination side edge node device. An optical path allocation request packet is used for this notification.

[0039] The above mentioned "cut-through request packet" and the "optical path allocation request packet" may be collectively called the "optical path control packet".

(B-2-4) Optical Path Switching Control Part 2B4

[0040] The optical path switching control part 2B4 is a functional part for the node device 2 to actually set the cut-through optical path according to the instructions of the received optical path allocation request packet.

[0041] When the reception of the optical path allocation request packet is confirmed, the optical path switching control part 2B4 controls the optical cross-connect 2C according to the instructions of this packet, and sets the cut-through optical path in the present node device. When the setting of the cut-through optical path completes, the optical path switching control part 2B4 transmits the optical path setting completion notice packet and notifies the completion to the transmission side edge node device.

(B-2-5) Router Control Part 2B5

[0042] The router control part 2B5 is a functional part for notifying completion of the setting of the cut-through optical path to the router 2A, and instructing the router 2A to transfer a series of packets via the cut-through optical path from there on.

[0043] The router control part 2B5 can release the newly set cut-through optical path when a predetermined time has elapsed since the initial setting, or when an event occurs, such as a decrease in the number of communication packets (from the threshold) at the node device positioned at both ends of the cut-through optical path. Release here may be a physical release or may be a logical release, where the setting status remains but the path is regarded as an available resource so that the setting is changed when a new optical path setting is requested.

[0044] The decrease in the number of communication packets at the node device positioned at both ends of the cut-through path is notified via a dedicated communication line (optical path or electric wire) disposed between the node devices or via several hops of other optical paths displaced between the node devices.

(B-3) Optical Path Setting Operation

[0045] Next the optical path setting operation by the node device (node control device, optical path setting method) having the above mentioned functional configuration will be described. Fig. 4 shows a setting of an optical path for cut-through in an optical network. In Fig. 4, only an outline of the node device 2 is shown. Also in Fig. 4, the left end is the upstream side of the path route and the right end is the downstream side of the path route. In other words, the node device 2S at the left end operates as the transmission side edge node device, the node device 2R at the right end operates as the destination side edge node device, and the two node device 2M1 and 2M2 disposed between these operate as the core node device.

(1) Transfer of User Packet

[0046] In the first step shown in Fig. 4 (A), the first user packet for a destination arrives from a terminal (or a net in an access system) to a node device 2S (transmission side edge node device at the left in Fig. 4) accommodating the destination.

[0047] At this time, the node device 2S (that is, the transmission side edge node device) transfers the packet to the next transfer destination, that is, the node device 2M1, according to the optical path and routing table currently set at the router 2A of the node device 2S.

[0048] The node device 2M1, to which the first packet was transferred, transfers the packet to the node device 2M2 which is the next transfer destination in the same way, as long as the node device 2M1 is not the destination side edge node device. The first packet is eventually transferred to the node device 2R, (that is, the destination side edge node device) accommodating the destination terminal (or net of an access system), and is transferred to the destination via the router 2A of the node device 2R.

[0049] In the above transfer operation, transfer is executed by the routing function of the router 2A without intervention of the node control function part 2B. The flow of the packet shown by the arrow marks in Fig. 4 (A) shows this transfer operation.

(2) Transfer of Cut-through Request Packet

[0050] The next step is started by the destination side edge node device 2R. The router 2A of each node device 2 (2S, 2M1, 2M2, 2R) has a function to transfer the packet to the node control function part 2B, as well as transferring the packet to the next transfer destination, when the destination of the user packet is the terminal (or net of an access system) of the concerned node device, that is, the present node device. (This function is shown by an arrow mark (broken line) in Fig. 4 (A), for example.)

[0051] When the node control function part 2B of the node device 2R receives the user packet, the node control function part 2B confirms that the node device which the node control function part 2B belongs to is the destination edge node device using the edge/core determination part. Then this function part 2B starts up the cut-through request packet processing part 2B2, and transmits the open resource information (e.g. wavelength) to the upstream side as a cut-through request packet (Fig. 4 (B)).

[0052] The cut-through request packet transferred to the node device (core node device) 2M2 at the upstream side is routed by the router 2A of the core node device 2M2, and is sent to the node control function part 2B. The node control function part 2B of the core node device 2M2, as well, confirms the position of the present device, that is, the core node device 2M2, using the edge/core determination part 2B, just like the case of the node control function part 2B of the destination side edge node device. Then this function part 2B starts up the cut-through request packet processing part 2B2, and adds the open resource information (e.g. wavelength) of the present node device itself to the cut-through request packet and transfers the packet. This operation is executed repeatedly.

(3) Transfer of Optical Path Allocation Request Packet

[0053] The cut-through request packet eventually reaches the transmission side edge node device 2S. This node device 2S receives the cut-through request packet, then confirms that the present node device is the transmission side edge node device 2S. After this confirmation, the node device 2S starts up the optical path allocation request packet processing part 2B3 of the present node device 2S. By this startup, this processing part 2B3 calculates the optimum allocation of the optical path based on the information written in the cut-through request packet (e.g. node information on current set route and open resource information).

[0054] When the optimum allocation of the optical path is determined, the optical path allocation request packet processing part 2B3 transmits the optical path allocation request packet to each node device 2S, 2M1, 2M2 and 2R on the route, including the present node device 2S, and notifies the calculation result. This packet is transferred sequentially to the downstream side, as shown in Fig. 4 (C).

[0055] When the present node device is included in one of the destinations of transfer of the optical path allocation request packet, the packet is loaded to the node control function part 2B in the present node device (core node device), and the optical path allocation request packet processing part 2B3 is started up. And the optical path allocation request packet processing part 2B3 confirms the allocation to set the cut-through optical path.

(4) Transfer of Optical Path Setting Completion Notice Packet

[0056] In each node device, after the optical path allocation request packet processing part 2B3 confirms the allocation of the optical path, the optical path switching control part 2B4 executes the actual switching of the optical cross-connect 2C. In other words, an optical path, which omits the router 2A (communication path for user packets which does not go through the router 2A), is set for the optical cross-connect 2C.

[0057] Completion of the optical path setting is notified to the transmission side edge node device 2S. This notification is performed by core node devices 2M1 and 2M2 adding information on completion of the optical path setting at the respective node devices to the optical path setting completion notice packet transmitted from the destination side edge node device 2R, and transferring the packet with this added information to the transmission side edge node as shown in Fig. 4 (D).

(5) Transfer of User Packet

[0058] After this, completion of the setting of the cut-through optical path is notified to the router 2A by the router control part 2B5 of the node function part 2B, and hereafter, use of the cut-through optical path is commanded for the series of transfers of packets.

[0059] Fig. 4 (E) shows the status after the cut-through optical path is allocated. As Fig. 4 (E) shows, the optical path 4, which does not go through the router 2A, is set at the part of the core node device 2M1 and 2M2. Hereafter, a user packet is transferred via this cut-through optical path 4.

[0060] In the above mentioned embodiment, the node control function part 2B of the transmission side edge node device 2S calculates the optimum allocation of the optical path such that the number of relay hops by the router 2A on the route from the transmission side edge node device 2S to the destination side edge node device 2R becomes a minimum. In other words, the node control function part 2B calculates the allocation of the optical path so as to be relayed in the optical cross-connect 2C and to omit the router 2A.

[0061] This, however, does not mean that the optical path must be set to one hop without passing at all through the routers 2A of the core node device 2M1 and 2M2, which are located on the route from the transmission side edge node device 2S to the destination side edge node device 2R.

[0062] This is because as packet forwarding processing required at the router 2A decreases, the load applied to the router 2A decreases by that, and an improvement of throughput and a decrease in delay time can be achieved.

[0063] Even if the number of cut-through is not the maximum, it is possible to set the optical path based on another effective index, such as an improvement of

throughput or a decrease in delay time in the entire optical network system.

[0064] Possible handling methods of a user packet, for which transfer via the cut-through optical path is demanded, are a method of allowing the user packet to standby in the node device until a new cut-through optical path is set, and a method of transferring the user packet via an old conventional path until a new cut-through optical path is set, then the path for packet transfer is changed after setting.

[0065] In the above mentioned configuration example, when the cut-through request packet processing part 2B2 receives a cut-through request packet from the downstream side for the present node device, the cut-through request packet processing part 2B2 adds the information on the present node device to this packet, and transfers the packet to the upstream side. However, this configuration may be such that the cut-through request packet is directly transmitted to the transmission side edge node device from the processing part 2B2, without waiting for the packet from downstream.

[0066] Also, in the above configuration example, the transmission side edge node device, which received the cut-through request packet, transmits the optical path allocation request packet. However, transmission of the packet need not be executed from the transmission side edge node device.

(B-4) Effect of the Embodiment

[0067] By disposing the node device (node control device, optical path setting method) having the functional configuration in accordance with the present embodiment, it becomes possible to omit the layer 2 and layer 3 processing. Therefore the load to be applied to the router 2A can be decreased dramatically compared with a conventional system. So an improvement of throughput and a decrease of delay time can be implemented in a packet transfer. As a consequence, if this optical network system is used for Internet service, for example, the user will experience such benefits as quicker response times.

[0068] In the case of conventional systems, an optical path set once is basically used with that setting, and is not switched according to the traffic of IP packets. The present invention allows optimizing the setting of an optical path (e.g. decreasing the number of hops in an IP router).

(C) Second Embodiment

(C-1) Functional Configuration

[0069] The second embodiment will now be described with reference to Fig. 5. The second embodiment corresponds to a modification form of the node device in accordance with the above mentioned first embodiment, and the configuration of the functional parts 1A - 2C, and each part 2B1 - 2B5 constituting the node control function part 2B are essentially the same as the case of the first embodiment shown in Fig. 5.

[0070] The difference is that the transfer direction of the optical path control packets (cut-through request packet and optical path allocation request packet) in the second embodiment concerning the setting of the cut-through optical path is the opposite from the first embodiment.

[0071] This is seen by comparing Fig. 6, which shows the status of setting the optical path for cut through in the present embodiment, and Fig. 4, which shows the status of setting the optical path for cut through in the first embodiment. As Fig. 6 and Fig. 4 show, the transfer directions of Figs. 6(B) - 6(C) are opposite the transfer directions of Figs. 4(B) - 4(C) respectively. This is the biggest difference when the optical network system is constructed by disposing the node device 2 in accordance with the present embodiment.

(C-2) Configuration of Node Control Function Part 2B

[0072] Next the configuration of the node control function part 2B, which is the cause of the difference of the transfer direction of the optical path control packets, will be described. Here, functional parts which are the same as those of the first embodiment are denoted with the same signs as Fig. 1, and functional parts which are different from those of the first embodiment are denoted with corresponding signs and a prime (').

[0073] The node control function part 2B, constituting the node device 2 in accordance with the present embodiment, comprises the following five functional parts.

(a) Edge/core determination part 2B1
(b) Cut-through request packet processing part 2B2'
(c) Optical path allocation request packet processing part 2B3'
(d) Optical path switching control part 2B4
(e) Router control part 2B5

[0074] The three functional parts 2B2' and 2B3', where functions are different from the first embodiment, will now be described. The only actual change from the first embodiment is that the transfer direction of the packet related to the setting of the cut-through optical path is reversed.

(C-2-1) Cut-through Request Packet Processing Part 2B2'

[0075] The cut-through request packet processing part 2B2' of the present embodiment as well is for collecting the optical path resouce and traffic information required for setting a cut-through optical path.

[0076] When the node device to which this cut-through request packet processing part 2B2' belongs is determined as the transmission side edge node device 2S, this processing part 2B2' notifies the information on existence of the packet, which passed the present node device, and the open resource and traffic information (e.g. wavelength) of the present node device as the cut-through request packet to the node device 2M2, which is positioned next to the present node device 2R at the downstream side (destination side).

[0077] If reception of the cut-through request packet is confirmed and the present node device is determined as the core node device for this packet by the edge/core determination part 2B1, the cut-through request packet processing part 2B2 adds the open resource and traffic information of the present node device to the received cut through request packet, and transfers the packet to the node device at the down-stream side.

(C-2-2) Optical Path Allocation Request Packet Processing Part 2B3'

[0078] The optical path allocation request packet processing part 2B3' of the present embodiment as well is for determining the allocation of a cut-through optical path based on the collected open resource and traffic information, and for requesting to set the cut-through optical path based on this allocation.

[0079] For example, when reception of a cut-through request packet is confirmed and the edge/core determination part 2B1 determines that the present node device is the destination side edge node device 2R for this packet, the optical path allocation request packet processing part 2B3' calculates the optimum allocation of the optical path based on the open resource information and other information like traffic flowing this node included in the packet, and notifies the cut-through optical path setting request based on the result to the present node device, the core node device 2M1 and 2M2, and the transmission side edge node device 2S. An optical path allocation request packet is used for this notice.

(C-3) Optical Path Setting Operation

[0080] As mentioned above, the content of the functions to be executed by each function part is essentially the same as that of the first embodiment, with the exception of a difference in the directions of receiving or transmitting packets related to the operation.

[0081] Therefore, except for the transfer directions of these related packets, the optical path setting operation of the present embodiment progresses in the same manner as the first embodiment. After a new cut-through optical packet, which omits the layer 2 and layer 3 processing in the core node device, is set, a transfer at high throughput and low delay time is implemented using that route (Fig. 6 (E)).

(C-4) Effect of the Embodiment

[0082] As mentioned above, in the case of the node device (node control device, optical path setting method) having a functional configuration in accordance with the present embodiment as well, a similar effect as the first embodiment is possible, that is, the load to be applied to the router 2A can be decreased dramatically by the cut through on the optical layer (layer 1) compared with a conventional system, so an improvement of throughput and a decrease of delay time can be implemented in a packet transfer. As a consequence, if this optical network system is used for Internet service, for example, the user will experience such benefits as quicker response times.

[0083] The first embodiment, where the transmission side edge node device determines the optical wavelength and setting blocks to be used for cut through, may be advantageous in the case of (1) below. However, in the case of (2) below, the present embodiment is more advantageous than the first embodiment.

(1) The amount of packets which flow into the optical network system is about the same from any transmission side edge device 2S, and load is concentrated on the destination side edge node device 2R, which is the destination of the packets. (Reason: The setting of optical wavelength and setting blocks can be processed and distributed by the transmission side edge node device 2S, where load is not concentrated.)

(2) Node device which sends the packets to the optical network system is concentrated to a specific transmission side edge node device 2S. (Reason: The setting of optical wavelength and setting blocks can be processed and distributed by the destination side node where load is not concentrated.)

(D) Third Embodiment

(D-1) Functional Configuration

[0084] Next the third embodiment will be described with reference to Fig. 7. In the third embodiment, a node device for which an optical path for cut through can be set at a higher speed than the above mentioned node device in accordance with the first and second embodiments will be described. In this node device 2 as well, the basic functional configuration is a router 2A, node control function part 2B, and an optical cross-connect 2C, which is the same as the case of the first embodiment.

[0085] The difference is the content of the function parts constituting the node control function part 2B. Therefore, in the following description, primarily the difference in configuration of the node control function part

2B will be described.

(D-2) Configuration of Node Control Function Part 2B

[0086] The node control function part 2B in accordance with the present embodiment comprises the following four function parts. Here, function parts which are the same as those of the first embodiment are denoted with the same signs, and functional parts which are different from those of the first embodiment are denoted with the corresponding sign and a prime (').

(a) Edge/core determination part 2B1
(b) Cut-through setting packet processing part 2B6
(c) Optical path switching control part 2B4'
(d) Router control part 2B5

[0087] These four functional parts 2B1, 2B6, 2B4' and 2B5 will now be described. Denoted with the same signs [as the first embodiment], the edge/core determination part 2B1 and the router control part 2B5 have the same functions as the case of the first embodiment, therefore descriptions are omitted.

(D-2-1) Cut-through Setting Packet Processing Part 2B6

[0088] The cut-through setting packet processing part 2B6, which is a configuration unique to the present invention, is a function part for setting the cut-through optical path autonomously using the optical wavelength resource notified from the downstream side, and notifying the open resource information (e.g. wavelength) of the node device to which this processing part 2B6 belongs by transferring a cut-through setting packet.

[0089] If cut through can be set using the optical wavelength resource notified from the downstream side, the cut-through setting packet transmission part 2B6 adds information on the cut-through optical path to be set to the received cut through setting packet, and transfers this packet to the node device at the upstream side.

[0090] If cut through cannot be set using the optical wavelength resource notified from the downstream side, on the other hand, the cut-through setting packet transmission part 2B6 transfers information on cut through, which has been set thus far, and open resource information in the present node device, to the node device at the upstream side together.

[0091] When the node device 2 corresponds to the destination side edge node device 2R, the cut-through setting packet transmission part 2B6, which confirmed existence of the packet which passed through the present node device, notifies existence of the packet which passed through and open resource information (e.g. wavelength) of the present node device to the node device at the upstream side as the cut-through setting packet.

(D-2-2) Optical Path Switching Control Part 2B4'

[0092] The optical path switching control part 2B4' is a functional part for actually setting the cut-through optical path for the resources for which the cut-through setting packet processing part 2B6 determined that the cut-through optical path can be set. The optical path switching part 2B4 controls the optical cross-connect 2C and sets the cut-through optical path in the present node device.

(D-3) Optical Path Setting Operation

[0093] Next the optical path setting operation by the node device (node control device, optical path setting method) having the above mentioned functional configuration will be explained. Fig. 8 shows the status when an optical path for cut through is set on the optical network.

[0094] As Fig. 8 shows, in the case of the present embodiment, time until setting of the optical path is shorter compared with the above mentioned first and second embodiments. This is because in the case of the first and second embodiments, the open resource information of all node device on the communication route is collected at either the destination side (first embodiment) or the transmission side (second embodiment) first, then the allocation of the optical path is set based on that information. In the case of the third embodiment however, the procedure for setting of optical path allocation used for the first and second embodiment is not used, so time until the optical path setting can be decreased.

[0095] Operation of the optical path setting of each node device according to the third embodiment will now be described. In the case of the present embodiment as well, the node device 2 (transmission side edge node device 2S at the left end of Fig. 8), which received a user packet from the terminal (or access system net) having a first packet for a certain destination, transfers the packet to the node device 2M, which is the next transfer destination, according to the optical path and routing table which are currently set in the router 2A of the present node device 2S so as to start a series of operations, which are the same as the first and second embodiments.

[0096] As Fig. 8 (A) shows, the first user packet is transferred sequentially by conventional routing processing in the node device, which is selected as a transfer destination, and eventually reaches the destination, side edge node device 2R.

[0097] The destination side edge node device 2R, which received the packet, outputs this user packet to the destination terminal (or access system net), but then returns the cut-through setting packet to the node device (core node device 2M2) at the upstream side from which the user packet was transferred. At this time, the open resource information on the destination side

node device 2R is notified.

[0098] When the core node device 2M2 (device next to the destination side edge node device 2R at the upstream side) receives the cut-through setting packet, the core node device 2M2 determines whether the open wavelength resource exists on the next device at both the upstream side and downstream side of the present node device 2M2, and if so, the core node device 2M2 determines that cut through is possible within the present node device 2M2, sets the cut-through optical path 4a (Fig. 8 (B)), and notifies this information to the upstream node device 2M1 and the downstream node device 2R.

[0099] This notice by the cut-through setting packet notifies the next core node device 2M1 at the upstream side (second device from the destination side edge node 2R at the upstream side) that the optical path 4a is set at the downstream side. In this case, the core node device 2M1 checks whether there is a wavelength resource for setting a cut-through optical path to connect with the cut-through optical path 4a, which has already been set at the downstream side, in the upstream side of the present node device. If such a resource exists, the core node device sets a new cut-through optical path 4b in the present node device, extends the conventional cut-through optical path 4a to the next node device 2M1 at the upstream side, notifies this to the next node device 2S at the upstream side, and the cut-through optical path 4 is set.

[0100] If setting of the cut-through optical path 4b is impossible, that information is notified to the upstream node device 2M1. By repeating this, setting of the cut-through optical path 4 between both the edge node devices 2S and 2R completes when the notice reaches the transmission side edge node device 2S (Fig. 8 (C)).

[0101] In this way, the subsequent user packet to be transferred is transferred using the cut-through optical path 4, that is, a high-speed transfer omitting the layer 2 and layer 3 processing can be implemented.

(D-4) Effect of the Embodiment

[0102] As mentioned above, if the node device (node control device, optical path setting method) having a functional configuration in accordance with the present embodiment, is disposed in the optical network system, it is possible to omit the IP layer (layer 3), and therefore load to be applied to the router 2A can be dramatically decreased compared with the conventional system. In this way, improvement of throughput and a decrease of delay time in a packet transfer can be implemented.

[0103] In the case of the node device in accordance with the present embodiment, a status where cut through is possible can be implemented when the cut-through setting packet, which was output from the destination side edge node device, reaches the transmission side edge node device. This can decrease the time until setting of the cut-through optical path compared with cases of the first and second embodiments.

[0104] In the case of the first embodiment and second embodiment, however, the cut-through optical path can be set for a longer block than the case of the third embodiment, since the optical path is set after collecting all information on all core node device which relay the transfer of a packet.

(D-5) A Modification Example

[0105] The above description on the third embodiment described a configuration for sequentially setting a cut-through optical path between the downstream side node device and the upstream side node device from the downstream side node device where a cut-through setting is possible. However, it is also possible to send a cut-through setting packet from the transmission side edge node device 2S to the destination side edge node device 2R, which is the reverse of the above case, and the cut-through optical path is sequentially set from the upstream side to the downstream side as soon as this packet arrives (Fig. 9).

(E) Fourth Embodiment

[0106] Next the fourth embodiment will be described with reference to Fig. 10. The fourth embodiment features the following functional part which is added to the node control function part 2B mounted in the node device 2 in accordance with the above mentioned embodiments, and corresponds to a modification form of the respective above mentioned embodiments.

[0107] Here, the new functional part to be added is called the cut-through optical path necessary/unnecessary determination function part 2B7. This cut-through optical path necessary/unnecessary determination function part 2B7 determines the necessity of setting the cut-through optical path before the setting operation described in the respective above mentioned embodiments actually start, and selectively sets the cut-through optical path only when it is determined as necessary.

[0108] In the above description, the necessity of setting a cut-through optical path is determined before transmitting the cut-through setting request packet, but in the case of the first embodiment or the second embodiment, the necessity is determined before transmitting the optical path setting request packet.

[0109] Specifically, the cut-through optical path necessary/unnecessary determination function part 2B7 judges the necessity of the cut-through optical path before the edge node device transmits the cut-through request packet (first or second embodiment) or, based on the following criteria, the cut-through setting packet (third embodiment).

[0110] The criteria used here is whether it is possible that a large volume of packets having the same

transmission origination address (SA) and the same destination address (DA) as a user packet having a new address transferred first, will be transferred on the optical network system in the future. This possibility is determined not only by determining whether it is possible that a large volume of packets will flow on the same route, but also whether the packets are application packets for which the requirement for delay times is strict (real-time packets).

[0111] Only when it is determined that setting of a new cut-through optical path is necessary, the cut-through request packet (first embodiment or second embodiment) or cut-through setting packet (third embodiment) described in the respective above mentioned embodiments is allowed to be transmitted.

[0112] Determining whether a new cut-through optical path is set based on the cut-through optical path necessary/unnecessary determination function part 2B7 need not be executed by the edge node device.

[0113] In this way, if the node device (node control device, optical path setting method) having a functional configuration in accordance with the fourth embodiment is disposed on the optical network system, the cut-through optical path is set only when a new path is necessary. In other words, the cut-through optical path is set only when a highly required service for the entire network or for a certain user is provided, therefore a system which exhibits minimal waste of wavelength resources can be constructed under current optical communication technology, where the number of wavelengths is limited to several ten to several hundred.

(F) Fifth Embodiment

[0114] With the current technology, if the arrangement of optical paths is frequently changed in the optical cross-connect, time for switching optical paths is wasted, since time requited for changing the setting of optical paths is longer than the speed of optical signals.

[0115] An object of the present embodiment is implementing a node device (node control device, optical path setting method) which can use the band of the optical path as effectively as possible, and implementing an optical network system where utilization of bandwidth of the optical path is efficient. Fig. 11 shows a configuration example of a node device in accordance with the present embodiment. For the node control function part 2B, one of the node control function part 2B (Fig. 1, Fig. 5, Fig. 7, Fig. 10), described in the first to fourth embodiments, is applied.

[0116] The configuration unique to the present embodiment is characterized by that the destination-based buffer 2D is disposed at some outputs of the router 2A constituting the node device 2. In other words, data output of the router 2A is input to the optical cross-connect (optical ADM) 2C via the destination-based buffer 2D.

[0117] The destination-based buffer 2D has a switch function part 2E which allows guiding the signal read from each buffer to an arbitrary input port of the optical cross-connect 2C. This switch function part 2E can be implemented in various way, such as a function of the optical cross-connect 2C side.

[0118] Next the IP packet transfer operation, which is implemented by the node device 2 in accordance with the present embodiment, will be described. When an IP packet is sent from a terminal (or access net), the node device 2 in the present embodiment once stores the IP packet in the destination-based buffer 2D. When a number of IP packets begin to store in the destination-based buffer 2D, cut-through optical path setting processing is executed by the node control function part 2B.

[0119] When the cut-through optical path is set, the IP packets, which have been stored in the destination-based buffer 2D thus far, are all transmitted to the destination side node device. After this transmission ends, this cut-through optical path is released. After releasing, this optical path is used for the transmission of IP packets stored in another destination-based buffer 2D. A description on the cut-through optical path setting operation is omitted here, since it is the same as the operation described in the respective above mentioned first to fourth embodiments.

[0120] The destinations of the IP packets stored in the destination-based buffer 2D need not be exactly the same. Even if the final destination is different, a packet can be effectively stored in the same destination-based buffer 2D if the packet passes through the same route.

[0121] If the node device (node control device, optical path setting method) having the functional configuration in accordance with the fifth embodiment is disposed in the optical network system, a decrease of load to be applied to the router 2A and an improvement of throughput can be implemented by setting the cut-through optical path, and also a limited band of optical signals can be more effectively used.

[0122] In particular, because the currently available commercial optical switches have relatively slow switching speeds, there is a demand to minimize the overhead required for switching time, that is, a demand to setting the optical path for a period of time while accumulating a number of IP packets without frequently switching the optical path. This method effectively satisfies such demand.

(G) Sixth Embodiment

[0123] Next the sixth embodiment will be described with reference to Fig. 12. The sixth embodiment corresponds to a modification form of the above mentioned fifth embodiment. The difference between the sixth embodiment and the fifth embodiment is that in the case of the sixth embodiment, an allowable delay recognition function part 2A1 is newly disposed in the router 2A constituting the node device 2. The allowable delay rec-

ognition function part 2A1 functions primarily at the transmission side edge node device.

[0124] This function part is provided for the purpose of adaptively preventing the occurrence of problems which may occur when the fifth embodiment is used alone. In other words, in the case of the fifth embodiment, an improvement of throughput and effective use of band are possible, but the delay time may become a problem. For example, in the case of packets of real-time system applications, such as an Internet TV telephone, service quality may drop if packets are stored for a predetermined time or longer.

[0125] In the node device in accordance with the present embodiment, the allowable delay recognition function part 2A1 of the router 2A first determines whether the current transfer target packet is a packet of a real-time system application such as an Internet TV telephone, or a packet of a non-real-time system application such as a file transfer. As a result of this determination, a packet transfer using the destination-based buffer 2D is selected only for the packet determined as the latter.

[0126] The node device in accordance with the present embodiment transfers a packet of a non-real-time system application (a packet to be stored in the destination-based buffer 2D) via the cut-through optical path, which is set in the optical layer (layer 1) when a certain number of packets accumulate (or by an event based on a certain time interval). Here, for the optical path to be used for a transfer of this packet, an optical path, where priority is assigned for efficient bandwidth utilization (an optical path which is set such that the number of cut-throughs become a maximum), for example, is used.

[0127] Another method is, for example, that some destination-based buffers are used for storing packets which cannot be delayed too long, and the packets stored in the buffers are output before the delay time becomes too long.

[0128] In this way, if the node device (node control device, optical path setting method) having the functional configuration in accordance with the sixth embodiment is disposed in the optical network system, packets of a real-time system application can be transferred without being delayed in a queue in the destination-based buffer, and has the features of the fifth embodiment as well.

(H) Seventh Embodiment

[0129] Generally speaking, and as mentioned in the above, the first to fourth embodiments are methods combining the basic concept, which is the dynamic allocation of an optical path and flow driven type multi-layer switch in an IP/ATM system, as mentioned above. However, the resource environment assumed in IP/ATM and the resource environment assumed in IP/Lightwave, which is described in the present description, are not always the same.

[0130] For example, in the case of IP/ATM, communication with an adjacent node device is insured if one logical channel is free, since ATM can set channels logically on a physical network.

[0131] In the case of IP/Lightwave, on the other hand, the method used for ATM cannot be used for a logical channel for an information transfer which has a narrow band, since the number of optical paths is restricted by the number of optical wavelengths multiplexed. Therefore, if all optical paths are allocated to omit the layer 2 and layer 3 processing in a node device of an optical network, this node cannot communicate with other node device.

[0132] If at least one optical path is free to communicate with another node device, it is certainly possible to communicate with any node device by using that optical path by repeatedly hopping. However, in this case, a large load is applied to the optical path.

[0133] In the node device in accordance with the present embodiment, it is proposed to dispose a function part for executing control to always keep free an optical path to be used as an information channel between the present node device and another node device. This function part is called an information channel insuring confirmation function part 2B8.

[0134] Fig. 13 shows a configuration example of the node device in accordance with the present embodiment. An information signal processing function part for exchanging information signals with another node device is disposed in the node control function part 2B, although the information signal processing function part is not illustrated in Fig. 13 (or in other drawing). Disposition of the information signal processing function part is the same for the above mentioned and later mentioned embodiments.

[0135] Although Fig. 13 shows a configuration where the information channel insuring confirmation function part 2B8 is added to the node device in accordance with the above mentioned sixth embodiment, it is certainly possible to apply the information channel insuring confirmation function part 2B8 in accordance with the present embodiment to each node device in accordance with the first to fifth embodiment.

[0136] Next the setting of a cut-through optical path by the node device having such a configuration will be described. When the node device 2 receives a request to omit the layer 2 and layer 3 processing by the optical layer (layer 1), the node device 2 confirms the existence and appropriateness of the open wavelength source of the present node device by function part of the node control function part 2B, and determines whether cut through is possible.

[0137] When the setting of the cut-through optical path is possible and the optical path is actually set, the node device 2 determines whether an information channel required for communication between the present node device and another node device is free by the

information channel insuring confirmation function part 2B8. If it is confirmed that a required information channel is free, the node device 2 actually executes switching to the optical path.

[0138] A general data packet can also be transferred to the optical path for an information channel insured in this manner. It is easiest to set this information channel between the present node device and an adjacent node device, but this approach is not an absolute. Even if some packet transfers are necessary (using a longer route), required information (packet) can reach its destination via the insured information channel.

[0139] As mentioned above, if the node device (node control device, optical path setting method) in accordance with the present embodiment is disposed in the optical network system, an information channel can always be insured between adjacent nodes, in addition to the effects of the respective above mentioned embodiments. Therefore such communication as releasing the setting of an optical path can always be directly executed.

(I) Eighth Embodiment

[0140] Next the eighth embodiment will be described with reference to Fig. 14. The above mentioned seventh embodiment is a configuration example based on a technical concept only to insure an information channel. Whereas in the present embodiment, which is a node device which sets a dedicated optical path in advance for an information channel, that is, allocates a certain optical wavelength dedicated to an information channel, so as to insure releasing the setting of the cut-through optical path, will be described.

[0141] To implement such a function, in the case of the node device 2 in accordance with the present embodiment, an optical path extraction/insertion (drop/add) part for the information channel 2F to extract (drop) optical signals with a specified wavelength from the optical fiber 3 or insert (add) optical signals with a specified wavelength into the optical fiber 3, is disposed in the node device.

[0142] The optical path extraction/insertion (drop/add) part for the information channel 2F functions in some cases as a means for extracting (dropping) optical signals for the information channel, which were transferred from another node device, from the optical fiber 3, and functions as a means for inserting (adding) optical signals for the information channel to another node device.

[0143] In other words, the optical path extraction/insertion (drop/add) part for the information channel 2F extracts (drops) an optical signal with a specified wavelength from the optical fiber 3, transfers the optical signal to the router 2A and guides the optical signal to the information signal processing function part (in the node control function part 2B) which processes information conveyed on the optical signal. The optical path extraction/insertion (drop/add) part for the information channel 2F also receives the information which the information signal processing function part (in the node control function part 2B) addressed to another node device via the router 2A, and inserts (adds) the optical signal with a specified wavelength, where this information is conveyed, to the optical fiber 3.

[0144] The basic operations of the cut-through optical path setting procedures, and the user packet transfer procedure, are the same as the cases of the other embodiments.

[0145] In this way, if the node device (node control device, optical path setting method) in accordance with the present embodiment is disposed in the optical network system, an information channel required for the transfer of information for switching of an optical path can be absolutely and physically insured.

(J) Ninth Embodiment

[0146] Next the ninth embodiment will be described with reference to Fig. 15. Unlike the above mentioned eighth embodiment, in the ninth embodiment, a dedicated optical path for the information channel is not set in advance, instead a pilot tone signal is overlaid on the normal cut-through optical path for user data so as to insure the information channel at all times.

[0147] The node device 2 in accordance with the present embodiment implements this function by the pilot tone signal transmission function part 2G disposed in the node device. By this function, information can be exchanged between adjacent nodes (or nodes slightly distant from each other), even if all or almost all optical paths in a node device 2 are set to the cut-through optical paths.

[0148] A certain effect can be expected when the present method is applied as is, but if a plurality of node device on the same path transmit pilot tone signals at the same time, a collision of pilot tone signals may occur at the node device furthest downstream, and transmitted information may not be received.

[0149] Therefore in the present embodiment, it is more effective to add the following means. For example, the pilot tone signals are transmitted in bursts only when information is transmitted. In this case, even if transmitted information cannot be received due to a collision of pilot tone signals, the node device furthest downstream can request a resend using the idle time of the information channel. Another example is predetermining to always reply an acknowledgment (ACK) to the transmission side whenever information is received normally, so that information is automatically resent if the acknowledgment (ACK) is not returned.

[0150] In this case, the probability of an occurrence of collisions can be further decreased if the node device at the upstream side executes a resend at different timing by some means (e.g. determining a time until a resend by random numbers).

[0151] If the node device (node control device, optical path setting method) in accordance with the present embodiment is disposed in an optical network system, an information exchange between adjacent node device (including node device slightly distant from each other) becomes possible, even if all or almost optical paths pass through the node device without layer 2 or layer 3 processing.

(K) Tenth Embodiment

[0152] Next the tenth embodiment will be described with reference to Fig. 16. Unlike the above mentioned ninth embodiment, in the present embodiment, an information channel is insured by time division multiplex (TDM) of pilot tone signals on a normal cut-through optical path for user data.

[0153] The node device 2 in accordance with the present embodiment implements this function by TDM pilot tone transmission function part 2H for the information channel which is disposed in the node device. Fig. 17 shows an example of time division multiplex (TDM) of pilot tone signals. In Fig. 17, with reference to time slots t1, t2 and t3 when the node device 2 (1) furthest upstream transmitted pilot tone signals, the node devices 2 (2), 2 (3) and 2 (4) in subsequent stages overlay respective information in different time slots (P1, P2, P3; q1, q2, q3) respectively.

[0154] For synchronization, the synchronous circuit used for receiving the pilot tone signals can be used as is. Cross-talk clearly does not occur on different optical paths, even if pilot tone signals with the same frequency are used.

[0155] In this way, if the node device (node control device, optical path setting method) in accordance with the present embodiment is disposed in the optical network system, information can be transferred without a collision of pilot tone signals occurring.

[0156] In the present embodiment, a TDM system is used for the transmission of pilot tone signals, but a transmitter-receiver for pilot tone signals with different frequencies may be provided in each device, so as to enable communication between the node devices by the transmitter-receivers. Here, as a rule, a different frequency for a pilot tone signal is assigned to each node device. However, if a pilot tone signal from another node device received by a node device which distance is sufficiently distant, is noticeably weak, the same frequency may be used in an appropriate spatial arrangement.

(L) Other Embodiments

[0157] In the above mentioned embodiments, the case when the layer 3 switch, where packets are transferred at high-speed based on the layer 3 (network layer) address of the input packet, was described for the node device 2, but the present invention can also be applied to the layer 4 switch where the header information of the layer 4 (transport layer) of the input packet, such as the port numbers of TCP and UDP, is read to transfer packets. In this case, processing for the layer 3 or layers higher than the layer 3 is omitted.

(M) Still Other Embodiments

[0158] In the above embodiments, the node device itself judges whether the self node device is at the transmission side or destination side edge node or core node device before executing the processing required for setting an optical path. To decrease cost to construct an optical network system, however, it is preferable that the node device have such a configuration that judging the role of the self node device is unnecessary. In other words, it is preferable, in terms of construction cost, to provide an optical network system by providing a node device where the edge node device and core node device are designed as dedicated for the respective edge node and core node.

[0159] Fig. 18 is a drawing depicting an example of a net where the optical network system is comprised of such dedicated node devices. In the configuration example in Fig. 18, the optical network is comprised of three edge node devices 10A, 10B and 10C (these edge node devices are collectively denoted by 10) and four core node devices 12A, 12B, 12C and 12D. The terminal 14A, LAN 16A and the core node device 12A are connected to the edge node device 10A. The terminals 14B, 14C and the core node device 12D are connected to the edge node device 10B. The terminal 14D, another network 18, and the core node device 12C are connected to the edge node device 10C. The core node device 12A is connected to the core node devices 12B and 12D respectively via optical fibers. The core node device 12B is connected to the core node devices 12D and 12C respectively via optical fibers, and the core node device 12C is connected to the edge node device 10C via optical fibers. The core node device 12D is connected to the edge node device 12B via optical fibers.

[0160] In the configuration example of this optical network system, an edge node device is connected only between an external terminal and a core node device. A core node device is connected only with one or both of an edge node device and another core node device. Therefore, a core node device has core node input/output ports to forward transfer packets with another core node device, but does not have input/output ports to forward transfer packets with an external terminal. The transfer packets include a user packet and a control packet.

[0161] The edge node device 10 dedicated to the edge is configured such that the edge/core judgment part 2B1 and the optical path switching control part 2B4 are omitted from the configuration of the node control part of the general edge node device 2, that is, the node control device 2B, which is described with reference to Fig. 2, and the optical transmission device, that is, a

simple input/output part, is used instead of the optical cross-connect 2C. Fig. 19 shows a configuration example of the edge node device 10 dedicated to the edge. In Fig. 19, the same components as in Fig. 2 are denoted with the same reference characters. However, the edge node control function part, which corresponds to the node control device 2B in Fig. 2, is denoted with 22B, the input/output part is denoted with 22C, and the edge node router is denoted with 22A.

[0162] The input part 22C has edge node input/output ports to forward transfer packets between the edge node device which includes this input part 22C and a core node device. These edge node input/output ports are comprised of an optical wavelength multiplexer/demultiplexer 2C3. And these input/output ports 2C3 are connected to the router 22A via the interface 2C1. The transfer packets include a user packet and a control packet.

[0163] The edge node router 22A has input/output ports for connection with an external terminal or LAN or another network. The edge node router 22A determines the output destination of the transfer packet which was input from the input/output ports according to the header information of layer 2 and layer 3, and outputs the output destination to the input/output part 22C.

[0164] The edge node control function part 22B controls the decision of the output destination in the router 22A according to the instruction of the transfer packet which was input thereto. Or, the edge node control function part 22B outputs the packet which was input from the input part 22C to an appropriate terminal interface.

[0165] The above mentioned transfer packets include a user packet and a control packet.

[0166] The edge node control function part has a cut-through request packet processing part 22B2, an optical path allocation request packet processing part 22B3, and an edge node router control part 22B5.

[0167] When a transfer packet from a transmission origination edge node device is input, the cut-through request packet processing part 22B2 notifies the open resource information in the self edge node device to the transmission origination edge node device as a cut-through request packet.

[0168] When the cut-through request packet from the destination side edge node device is input, the optical path allocation request packet processing part 22B3 decides an optimum optical path allocation based on the open resource information written in the cut-through request packet, and notifies the allocation to the core node device and the destination side edge node device as the optical path allocation request packet.

[0169] When a cut-through optical path is set in the core node device and the destination side edge node device, the edge node router control part 22B5 controls the edge node router 22A so that transfer packets are transferred via this cut-through optical path.

[0170] In the same manner, a core node device 12 dedicated to the core is configured such that the edge/core judgment part 2B1 and the optical path allocation request packet processing part 2B3 are omitted from the configuration of the node control part of the general edge node device 2, that is, the node control device 2B which was described with reference to Fig. 2. Fig. 20 shows a configuration example of the edge node device 12 dedicated to the edge. In Fig. 20, the same components as the components in Fig. 2 are denoted with the same reference characters. However, the core node control function part, which corresponds to the node control device 2B in Fig. 2, is denoted with 32B, and the core node router is denoted with 32A.

[0171] The core node device 12 has core node input/output ports to forward the transfer packets with an edge node device or with another core node device, and has an optical cross-connect 2C for setting an optical path between input/output ports of this core node. In the configuration example in Fig. 19, the core node input/output ports are comprised respectively of an optical wavelength multiplexer/demultiplexer 2C3, which constitutes a part of the optical cross-connect 22C.

[0172] The core node router 32A decides the output destination of the transfer packet which was input from the core node input/output part 2C3 according to the header information of layer 2 and layer 3, and outputs the output destination to the core node input/output part 2C3.

[0173] The user packets which are input to the same node device pass through only the optical cross-connect via the optical path, or are transferred to a router and is routed to an appropriate output destination in the router.

[0174] For a control packet, the core node control function part 32B decides the output destination in the core node router 32A according to the instruction of the control packet which was input, and controls the switching of a connected pair of each input port and output port inside the optical cross-connect 2C.

[0175] The core node control function part 32B has a cut-through request packet processing part 32B2, an optical path switching control part 32B4, and a core node router control part 32B5.

[0176] The cut-through request packet processing part 32B2 adds an open resource information in the self core node device to the cut-through request packet which is received from the upstream side or is independently generated and transfers the packet to the upstream side.

[0177] The optical path switching control part 32B4 sets a cut-through optical path in the optical cross-connect 2C according to the instruction of the optical path allocation request packet notified from the edge node device.

[0178] When a cut-through optical path is set in a core node device and a destination side edge node device, the core node router control part 32B5 controls the core node router 32A so that the transfer packet is

transferred via this cut-through optical path.

[0179] In the case of the optical network system having the configuration shown in Fig. 18, the function of the router is not always necessary, but only the optical cross-connect can create a state where an optical path from an edge node to another edge node is always set. In this case, control can be executed by control signals (control packet), for example, which are sent by a pilot tone.

Claims

1. A node control device (2B) which is disposed in each node device (2) constituting an optical network system (Fig. 3 and Fig. 4), and is used for controlling the packet transfer operation in each node device, characterized in comprising:

   edge/core determination means (2B1) for determining whether a node device (2) which the node control device (2B) is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device (2S), a core node device (2M1, 2M2), or a destination side edge node device (2R) for the transfer packet which is to be processed;
   cut-through request packet processing means (2B2) wherein which, when said present node device is the destination side edge node device, notifies the open resource information of said present node device to the upstream side of the transfer route as a cut-through request packet, and, when said present node device is the core node device, transfers the cut-through request packet after adding thereto the open resource information of said present node device which is received from the downstream side of the transfer route or is individually generated;
   optical path allocation request packet processing means (2B3) for determining the optimum allocation of the optical path based on the open resource information of the cut-through request packet transferred to the transmission side edge node device, and notifying the allocation to the target transmission side edge node device, core node device, and destination side edge node device respectively by an optical path allocation request packet; and
   optical path switching control means (2B4) for controlling an optical switch (2C2) according to the allocation notified by the optical path allocation request packet, setting an optical path (4) which omits the layer 2 and 3 processing, and notifying the completion to the transmission side edge node device by an optical path setting completion notice packet.

2. A node control device (2B) which is disposed in each node device (2) constituting an optical network system (Fig. 3 and Fig. 6) and is used for controlling the packet transfer operation in each node device, characterized in comprising:

   edge/core determination means (2B1) for determining whether a node device (2) which the node control device (2B) is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device (2S), a core node device (2M1, 2M2), or a destination side edge node device (2R) for the transfer packet to be processed;
   cut-through request packet processing means (2B2') which, when said present node device is the transmission side edge node device, notifies the open resource information of said present node device to the downstream side of the transfer route as a cut-through request packet, and when said present node device is the core node device, transfers the cut-through request packet after adding thereto the open resource information of said present node device which is received from the upstream side of the transfer route or is individually generated;
   optical path allocation request packet processing means (2B3') for determining an optimum allocation of the optical path based on the open resource information of the cut-through request packet transferred to the destination side edge node device, and notifying the allocation to the target transmission side edge node device, core node device, and destination side edge node device respectively by an optical path allocation request packet; and
   optical path switching control means (2B4) for controlling an optical switch (2C2) according to the allocation notified by the optical path allocation request packet, setting an optical path which omits the layer 2 and layer 3 processing, and notifying the completion to the transmission side edge node device by an optical path setting completion notice packet.

3. A node control device (2B) which is disposed in each node device (2) constituting an optical network system, and is used for controlling the packet transfer operation in each node device, characterized in comprising:

   edge/core determination means (2B1) for determining whether a node device (2) which the node control device (2B) is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device (2S), a core node device (2M1, 2M2), or

a destination side edge node device (2R) for the transfer packet to be processed;

cut-through setting packet processing means (2B6) which, when said present node device is the destination side edge node device, notifies the open resource information of said present node device to the upstream side of the transfer route as a cut-through setting packet, and when said present node device is the core node device, determines whether cut through by the open resource indicated in the cut-through setting packet received from the downstream side of the transfer route is possible, and if possible, transfers received cut-through setting packet to the upstream side of the transfer route after adding the information to the cut-through setting packet, and if impossible, transfers received cut-through setting packet to the upstream side of the transfer route after adding thereto the cut-through information which has been set thus far and the open resource information of said present node device; and

optical path switching control means (2B4') which, when said cut-through setting packet processing means determines that cut through is possible, controls an optical switch (2C2) so as to set an optical path to the resource for which it was determined that cut through is possible.

4. A node control device (2B) which is disposed in each node device (2) constituting an optical network system (Fig. 3 and Fig. 9), and is used for controlling the packet transfer operation in each node device, characterized in comprising:

edge/core determination means (2B1) for determining whether a node device (2) which the node control device (2B) is controlling (hereafter to be referred to as the present node device) is a transmission side edge node device (2S), a core node device (2M1, 2M2), or a destination side edge node device (2R) for the transfer packet to be processed;

cut-through setting packet processing means (2B6) which, when said present node device is the transmission side edge node device, notifies the open resource information of said present node device to the downstream side of the transfer route as a cut-through setting packet, and when said present node device is the core node device, determines whether cut through by the open resource indicated in the cut-through setting packet received from the upstream side of the transfer route is possible, and if possible, transfers the received cut-through setting packet to the downstream side of the transfer route after adding the information to the cut-through setting packet, and if impossible, transfers the received cut-through setting packet to the downstream side of the transfer route after adding thereto the cut-through information which has been set thus far and the open resource information of said present node device; and

optical path switching control means (2B4') which, when said cut-through setting packet processing means determines that cut through is possible, controls an optical switch (2C2) so as to set an optical path to the resource for which it was determined that cut through is possible.

5. The node control device according to one of Claims 1 to 4, further comprising forced releasing means for forcibly releasing the optical path when a predetermined time has elapsed since setting of the optical path, or when a decrease in the number of communication packets is confirmed at the node device positioned at both ends of said optical path.

6. The node control device (2B) according to one of Claims 1 to 5, further comprising cut-through optical path necessary/unnecessary determination means (2B7) for determining the necessity of cut through before transmitting the cut-through request packet or transmitting the cut-through setting packet, so that the cut-through optical path is selectively set only when determined as necessary.

7. The node control device (2B) according to one of Claims 1 to 6, further comprising information channel insuring means (2B8) for determining whether the information channel is continuously insured after setting the cut-through optical path between the node devices on the route where the cut-through optical path is set before transmitting the cut-through request packet or transmitting the cut-through setting packet, and setting the cut-through optical path only when the information channel is insured.

8. A node device (2), characterized in comprising:

a router (2A) for determining the output destination of a transfer packet which is input according to the header information of the layer 3;

an optical cross-connect (2C) for extracting (dropping) optical signals from an optical fiber or inserting (adding) optical signals to an optical fiber, or relaying optical signals between arbitrary input/output optical fibers for optical path setting; and

a node control device (2B) according to one of the Claims 1 to 7 for switching a connected pair

of each input port and output port inside said optical cross-connect according to the instructions of the received transfer packet or based on self judgment.

9. The node device according to Claim 8, further comprising a switch (2E) which connects a destination-based buffer (2D) to some of the outputs from said router to said optical cross-connect, and can connect a packet read from said destination-based buffer to an arbitrary input port of said optical cross-connect.

10. The node device according to Claim 9, further comprising allowable delay recognition function means (2A1) provided in said router for determining the allowable delay of a transfer packet, so that only packets with a large allowable delay are allowed to be output to said destination-based buffer and packets with a small allowable delay are directly output to said optical cross-connect.

11. A node device (2), characterized in comprising:

a router (2A) for determining the output destination of a transfer packet which is input according to the header information of the layer 3;
an optical cross-connect (2C) for extracting (dropping) optical signals from an optical fiber, or inserting (adding) optical signals into an optical fiber, or relaying optical signals between arbitrary input/output optical fibers for optical path setting;
a node control device (2B) according to one of Claims 1 to 6 for switching a connected pair of each input and output port inside said optical cross-connect according to the instructions of the received transfer packet or based on self judgment; and
optical path extraction/insertion (drop/add) means (2F) for the information channel for extracting (dropping) optical signals with a fixed wavelength insured for the information channel from the optical fiber, or for inserting (adding) said optical signals with a fixed wavelength into the optical fiber, so as to enable communication of information signals with another node device.

12. A node device (2), characterized in comprising:

a router (2A) for determining the output destination of a transfer packet which is input according to the header information of the layer 3;
an optical cross-connect (2C) for extracting (dropping) optical signals from an optical fiber, or inserting (adding) optical signals into an optical fiber, or relaying optical signals between arbitrary input/output optical fibers for optical path setting;
a node control device (2B) according to one of Claims 1 to 6 for switching a connected pair of each input and output port inside the optical cross-connect according to the instructions of the received transfer packet or based on self judgment; and
pilot tone signal transmission means (2G) for the information channel for overlaying pilot tone signals for the information channel on the optical path for user data or separating pilot tone signals for the information channel from the optical path for user data so as to enable communication of information signals with another node device.

13. The node device according to Claim 12, wherein said pilot tone signals for the information channel are transmitted by a time division multiplex system.

14. An optical network system (Fig. 3, Fig. 4, Fig. 6, Fig. 8, Fig. 9) comprising a plurality of the node devices according to one of Claims 8 to 13.

15. An optical path setting method in an optical network system (Fig. 3, Fig. 4), characterized in comprising:

a step where a destination side edge node device (2R) which confirmed the transfer of a packet to a terminal accommodated by a present node device (2) or an access system network notifies the open resource information of said present node device to the transmission side edge node device (2S);
a step where the transmission side edge node device determines an optimum allocation of an optical path to be set on the transfer route based on the open resource information notified by the destination side edge node device and a core node device (2M1, 2M2); and
a step where the transmission side edge node device, the core node device and the destination side edge node device set the optical path which omits the packet transfer processing (layer 2 and layer 3 processing) in transit nodes for the optical path determined in the previous step.

16. An optical path setting method in an optical network system (Fig. 3, Fig. 6), characterized in comprising:

a step where a transmission side edge node device (2S) which confirmed the transfer of a packet to the destination notifies the open resource information of a present node device

(2) to a destination side edge node device (2R);

a step where the destination side edge node device determines the optimum allocation of the optical path to be set on the transfer route based on the open resource information notified by the transmission side edge node device and a core node device (2M1, 2M2); and

a step where the transmission side edge node device, the core node device and the destination side edge node device set the optical path which omits the packet transfer processing (layer 2 and layer 3 processing) in transit nodes for the optical path determined in the previous step.

17. An optical path setting method in an optical network system (Fig. 3 and Fig. 8), characterized in comprising:

a step where a destination side edge node device (2R) which confirmed the transfer of a packet to a terminal accommodated by a present node device (2) or to an access system network transmits the open resource information of said present node device to a transmission side edge node device (2S) which is at the upstream side; and

a step where a core node device (2M1, 2M2) and a transmission side edge node device, to which said open resource information is transferred, determine respectively whether the setting of a cut-through optical path is possible based on the open resource information received from the downstream side of the present node device, and if possible, the core node device and the transmission side edge node set the cut-through optical packet using the resource which was determined as possible, and notify the information to the upstream side, and if impossible, the core node device and the transmission side edge node device add the cut-through information which has been set thus far and the open resource information of the present node device to the received open resource information, and transfer it to the upstream side.

18. An optical path setting method in an optical network system (Fig. 3 and Fig. 9), characterized in comprising:

a step where a transmission side edge node device (2S) which confirmed the transfer of a packet to a destination transmits the open resource information of the present node device (2) to a transmission side edge node which is at the downstream side; and

a step where a core node device (2M1, 2M2) and the destination side edge node device (2R) to which said open resource information is transferred determine respectively whether the setting of a cut-through optical path is possible based on the open resource information received from the upstream side of the present node device, and if possible, the core node device and the destination side edge node device set the cut-through optical packet using the resource which was determined as possible, and notify the information to the downstream side, and if impossible, the core node device and the destination side edge node device add the cut-through information which has been set thus far and the open resource information of the present node device to the received open resource information, and transfer it to the downstream side.

19. The optical path setting method according to one of Claims 15 to 18, wherein the optical path is forcibly released when a predetermined time has elapsed since the setting of the optical path, or when a decrease in the number of communication packets is confirmed at the node device positioned at both ends of the optical path.

20. The optical path setting method according to one of Claims 15 to 19, wherein the necessity of cut through is determined before setting the cut-through optical path, and the setting processing is continued only when the necessity is determined.

21. The optical path setting method according to one of Claims 15 to 20, wherein it is determined whether the information channel is continuously insured after setting the cut-through optical path between the node devices on the route where the cut-through optical path is set before setting the cut-through optical path, and the cut-through optical path is set only when the information channel is insured.

22. The optical path setting method according to one of Claims 15 to 21, wherein a packet read from the destination-based buffer is transmitted to the cut-through optical path after setting.

23. The optical path setting method according to Claim 22, wherein only packets with a large allowable delay are stored in said destination-based buffer.

24. The optical path setting method according to one of Claims 15 to 20, 22 and 23, wherein the information communication between the node devices, where the cut-through optical path is set, is implemented using optical signals with a fixed wavelength insured for the information channel after the cut-

through optical path is set.

25. The optical path setting method according to one of Claims 15 to 20, 22 and 23, wherein the pilot tone signal for the information channel is overlaid on the optical path for user data to implement information communication between the node devices, where the cut-through optical path is set, after the cut-through optical path is set.

26. The optical path setting method according to Claim 25, wherein said pilot tone signals for the information channel are transmitted in the time division multiplex system.

27. An optical network system, characterized in comprising:

a plurality of edge node devices (10: 10A, 10B, 10C) which are designed as dedicated for respective edge nodes; and
one or more core node devices (12: 12A, 12B, 12C, 12D) which are connected between said plurality of edge node devices via a transfer route and are designed as dedicated for respective core nodes;
wherein said edge node device is connected only between an external terminal (14A, 14B, 14C, 14D, 16A and/or 18), etc. and the core node device; and
said core node device is connected only with both or one of said edge node device and another core node device, and has core node input/output ports for forwarding a transfer packet with the other core node device but does not have input/output ports for forwarding a transfer packet with an external terminal.

28. The optical network system according to Claim 27, wherein the transfer packets are packets including a user packet and a control packet; and said edge node device (10) further comprises:

input/output part (22C) having edge node input/output ports (2C3) for forwarding said transfer packet with said core node device;
an edge node router (22A) which has input/output ports, decides the output destination of said transfer packet which was input from said input/output ports in accordance with the header information of layer 2 and layer 3 and outputs the output destination to said input/output part; and
an edge node control function part (22B) which controls the decision of said output destination in said router for said user packet which was input according to the instruction of said control packet which was input;
and said core node device (12) further comprises:
an optical cross-connect (2C) which has code node input/output ports (2C3) for forwarding said transfer packet with said edge node device and with said other core node devices, and sets an optical path between said core node input/output ports;
a cord node router (32A) which outputs an output destination of a transfer packet which was input from said core node input/output ports according to the header information of layer 2 and layer 3, and outputs the output destination to said core node input/output part; and
a core node control function part (32B) which decides said output destination in said core node router for said user packet which was input according to the instruction of said control packet which was input, and controls the switching of a connected pair of each input port and output port inside said optical cross-connect.

29. The optical network system according to Claim 28, wherein said edge node control function part (22B) further comprises:

a cut-through request packet processing part (22B2) which, when a user packet from the transmission origination edge node device is input, notifies open source information of the self edge node device as a cut-through request packet to the transmission origination edge node device;
an optical path allocation request packet processing part (22B3) which, when a cut-through request packet is input from a destination side edge node device, decides an optimum allocation of an optical path based on the open resource information written in said cut-through request packet, and notifies said allocation to said core node device and said destination side edge node device as an optical path allocation request packet; and
an edge node router control part (22B5) which, when a cut-through optical path is set in said core node device and said destination side edge node device, controls said edge node router so that the user packet is transferred via said cut-through optical path;
and said core node control function part (32B) further comprises:
a cut-through request packet process part (32B2) which adds open resource information in the self core node device to the cut-through request packet which is received from an upstream side or is generated individually, and transfers it to the upstream side;

an optical path switching control part (32B4) which sets a cut-through optical path in said optical cross-connect according to the instruction of said optical path allocation request packet notified by said edge node device; and

a core node router control part (32B5) which, when a cut-through optical path is set in one of the core node devices and the destination side edge node device, controls said router so that the user packet is transferred via said cut-through optical path.

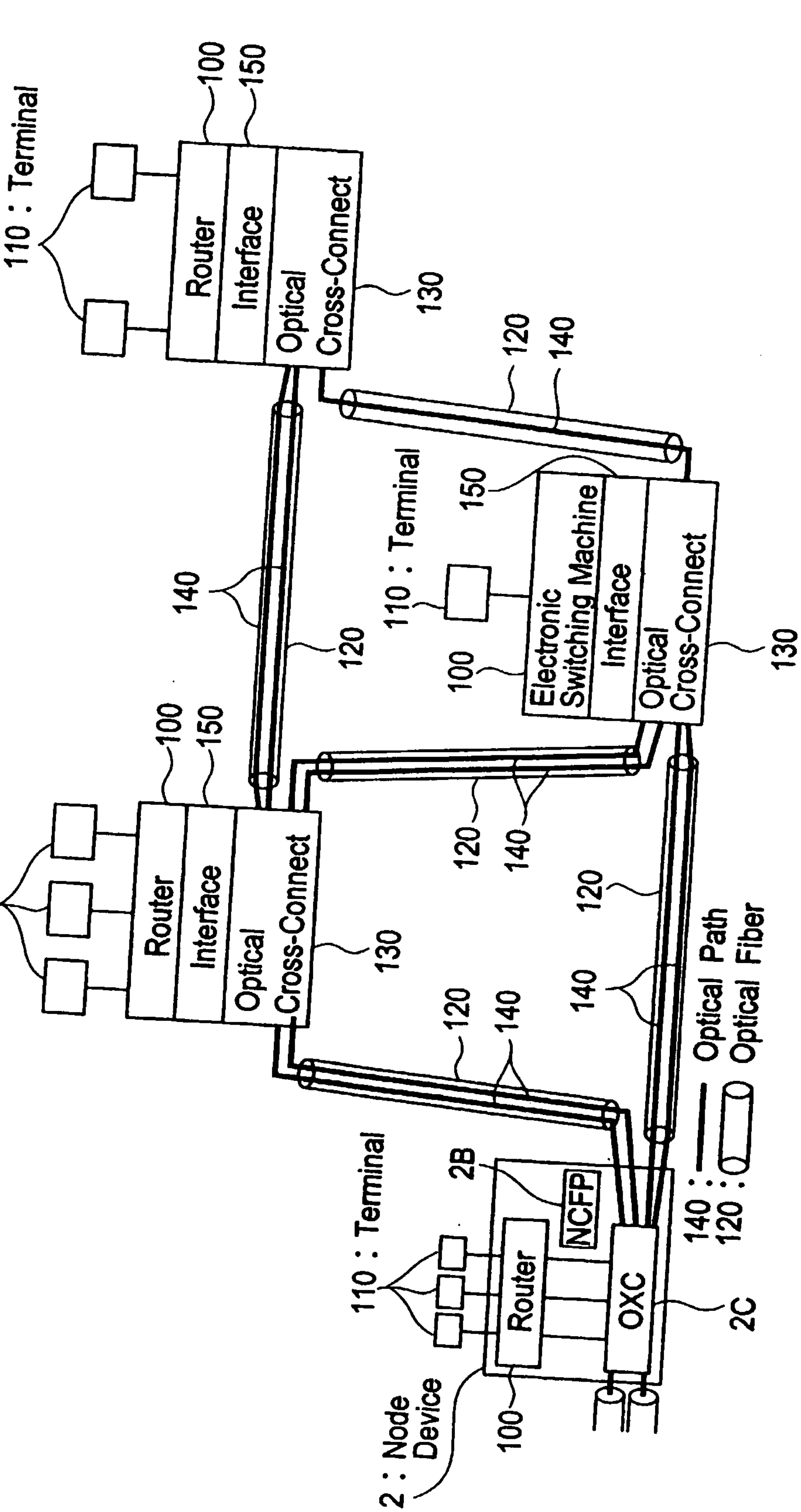

110 : Terminal
Router
Interface
Optical Cross-Connect
100
150
130
120
140
Electronic Switching Machine
2 : Node Device
OXC
NCFP
2B
2C
140 : Optical Path
120 : Optical Fiber

FIG. 1

FIG.2

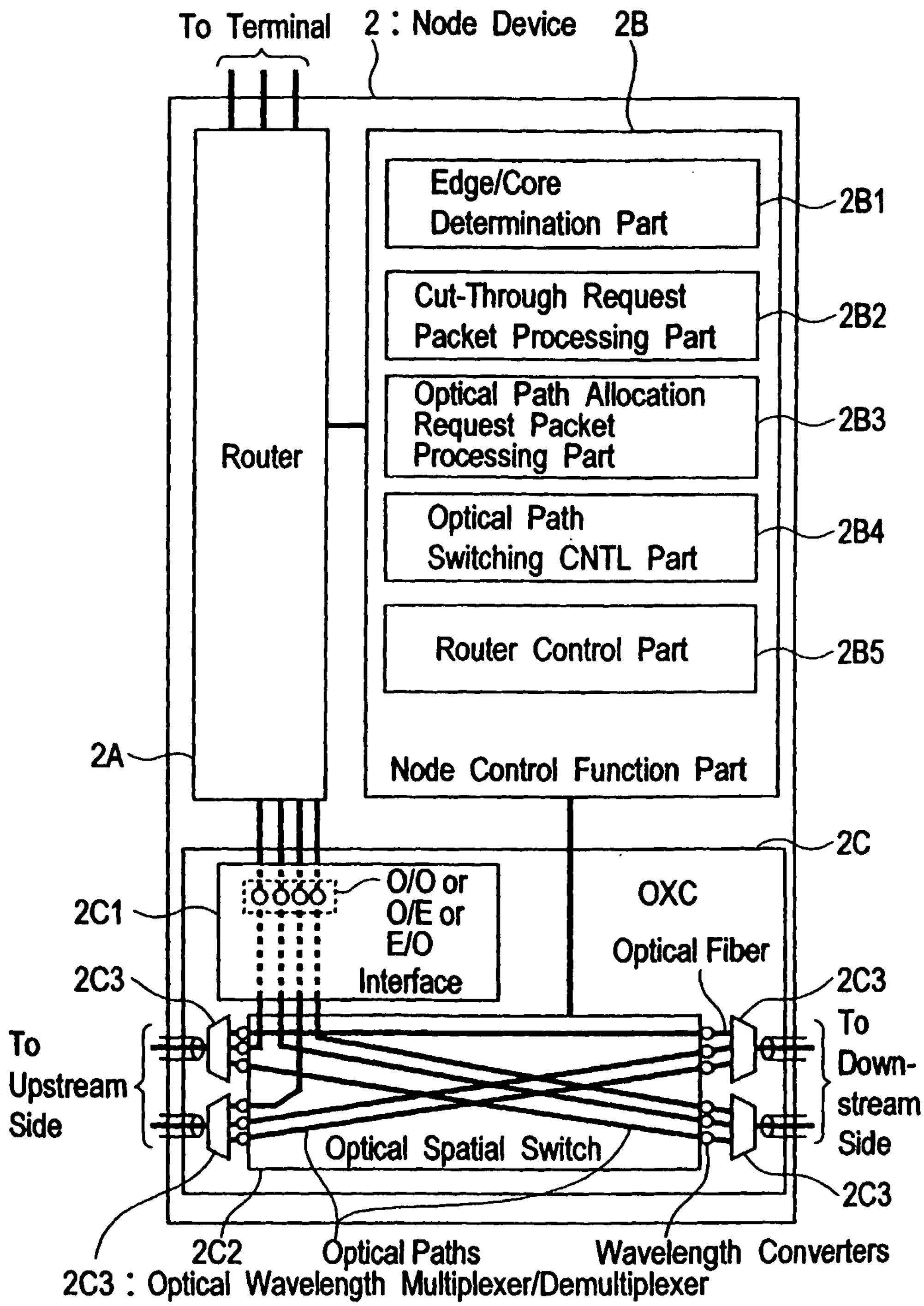
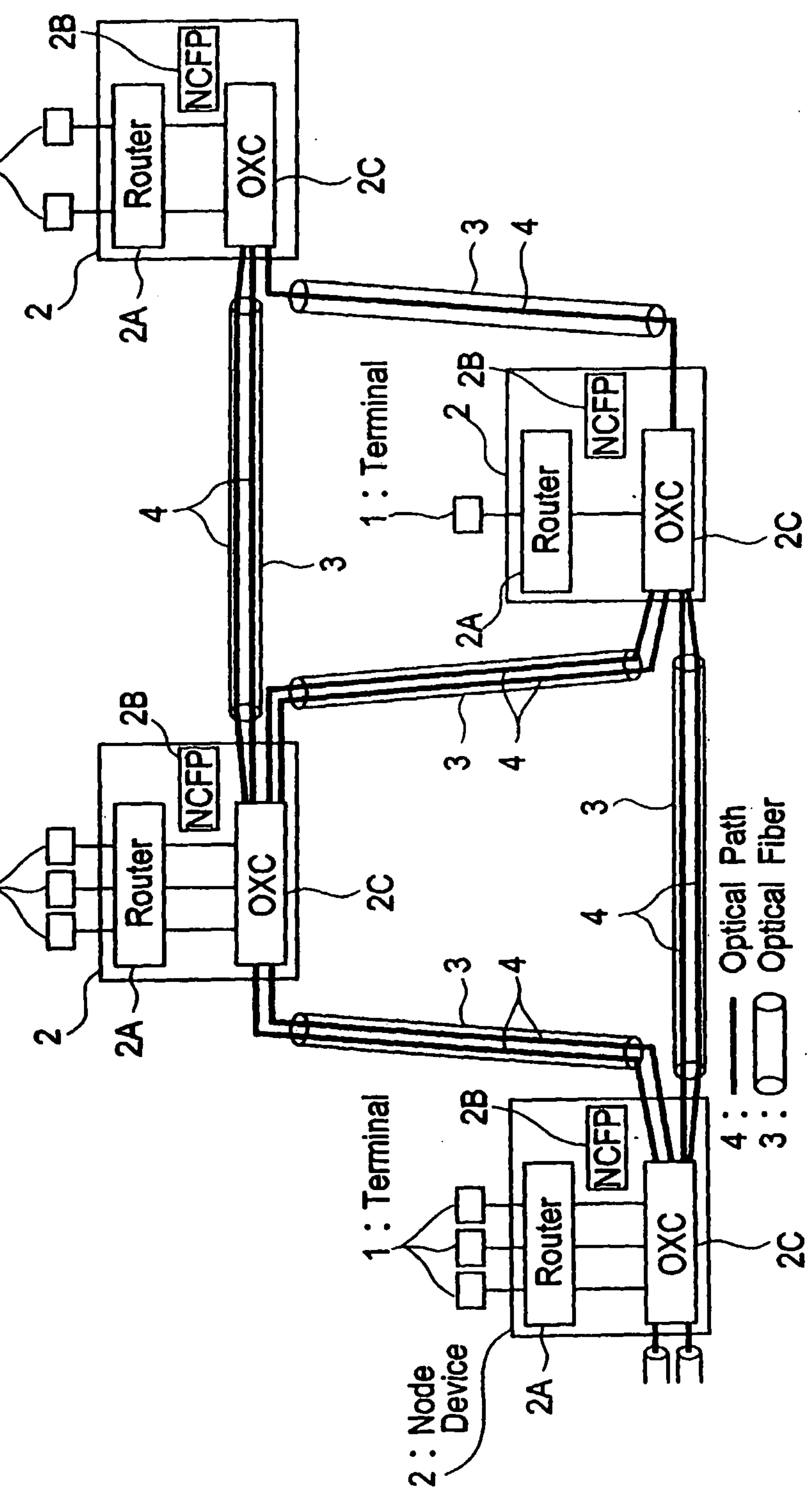

To Terminal
2 : Node Device
2B
Edge/Core Determination Part
2B1
Cut-Through Request Packet Processing Part
2B2
Optical Path Allocation Request Packet Processing Part
2B3
Router
Optical Path Switching CNTL Part
2B4
Router Control Part
2B5
2A
Node Control Function Part
2C
2C1
O/O or O/E or E/O Interface
OXC
Optical Fiber
2C3
2C3
To Upstream Side
To Down-stream Side
Optical Spatial Switch
2C3
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

FIG.3


1 : Terminal
2 : Node Device
Router
OXC
NCFP
2
2A
2B
2C
3
4
4 : Optical Path
3 : Optical Fiber

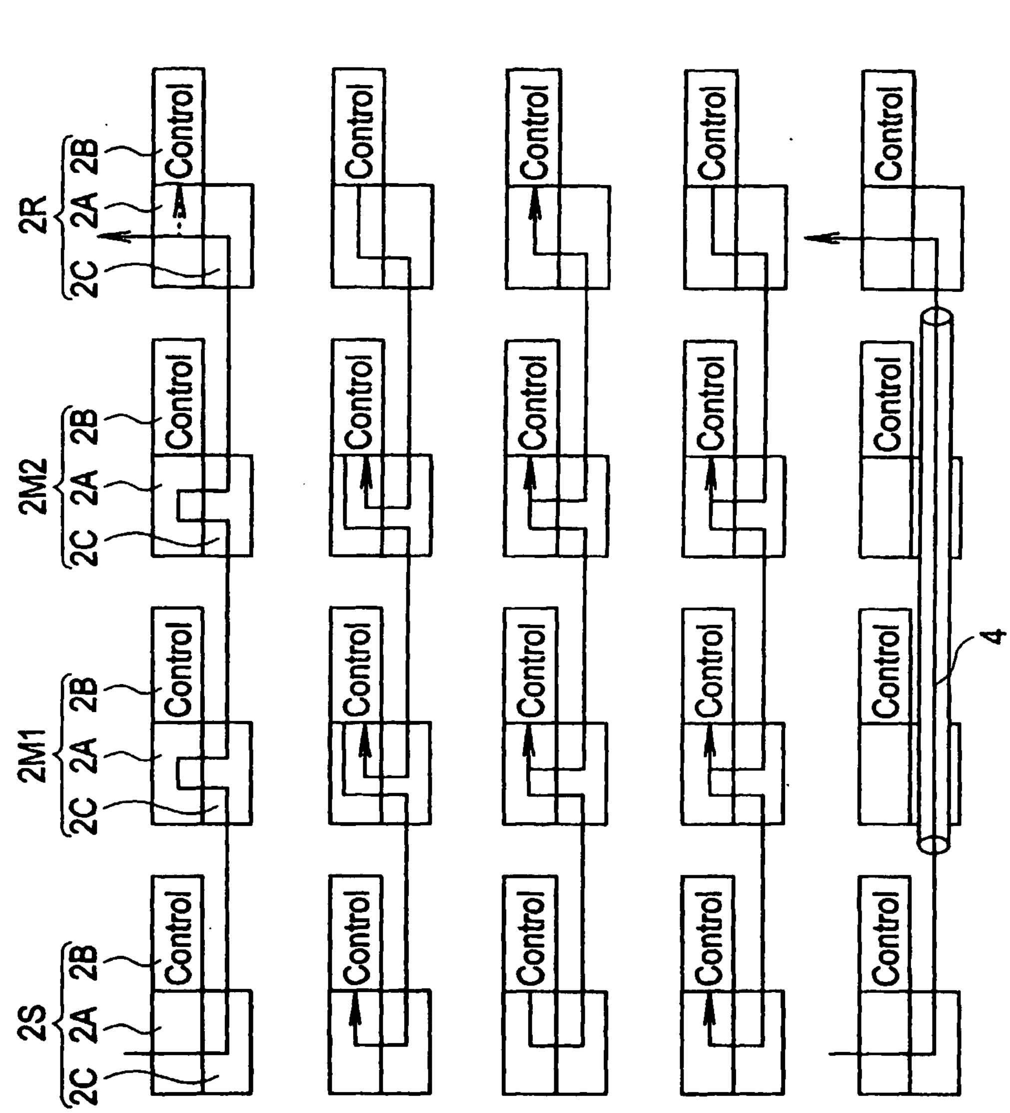


FIG. 4(A)

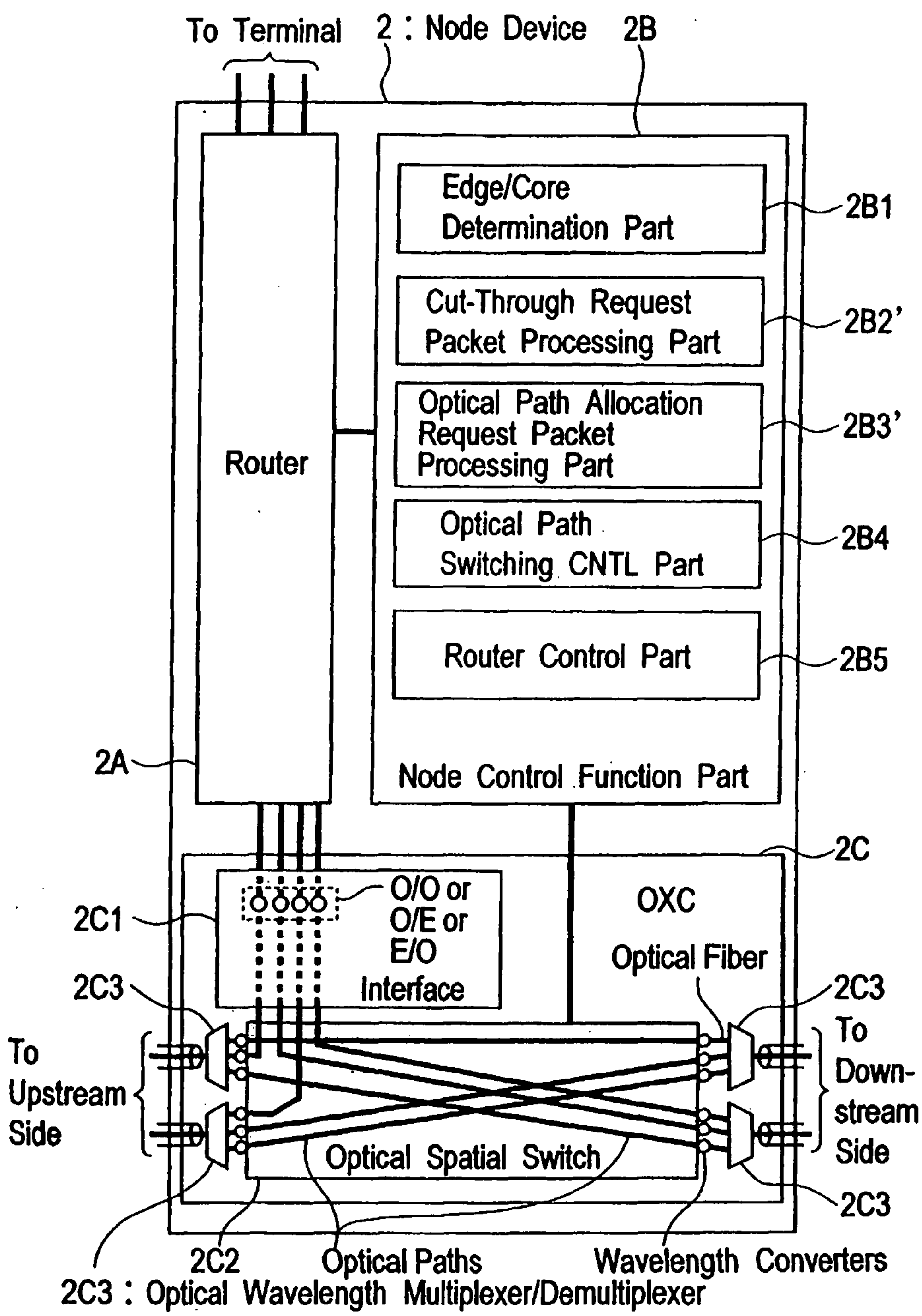
FIG. 4(B)

FIG. 4(C)

FIG. 4(D)

FIG. 4(E)

FIG.5


To Terminal
2 : Node Device
2B
Edge/Core Determination Part
2B1
Cut-Through Request Packet Processing Part
2B2'
Optical Path Allocation Request Packet Processing Part
2B3'
Router
Optical Path Switching CNTL Part
2B4
Router Control Part
2B5
2A
Node Control Function Part
2C
2C1
O/O or O/E or E/O Interface
OXC
Optical Fiber
2C3
2C3
To Upstream Side
To Down-stream Side
Optical Spatial Switch
2C3
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

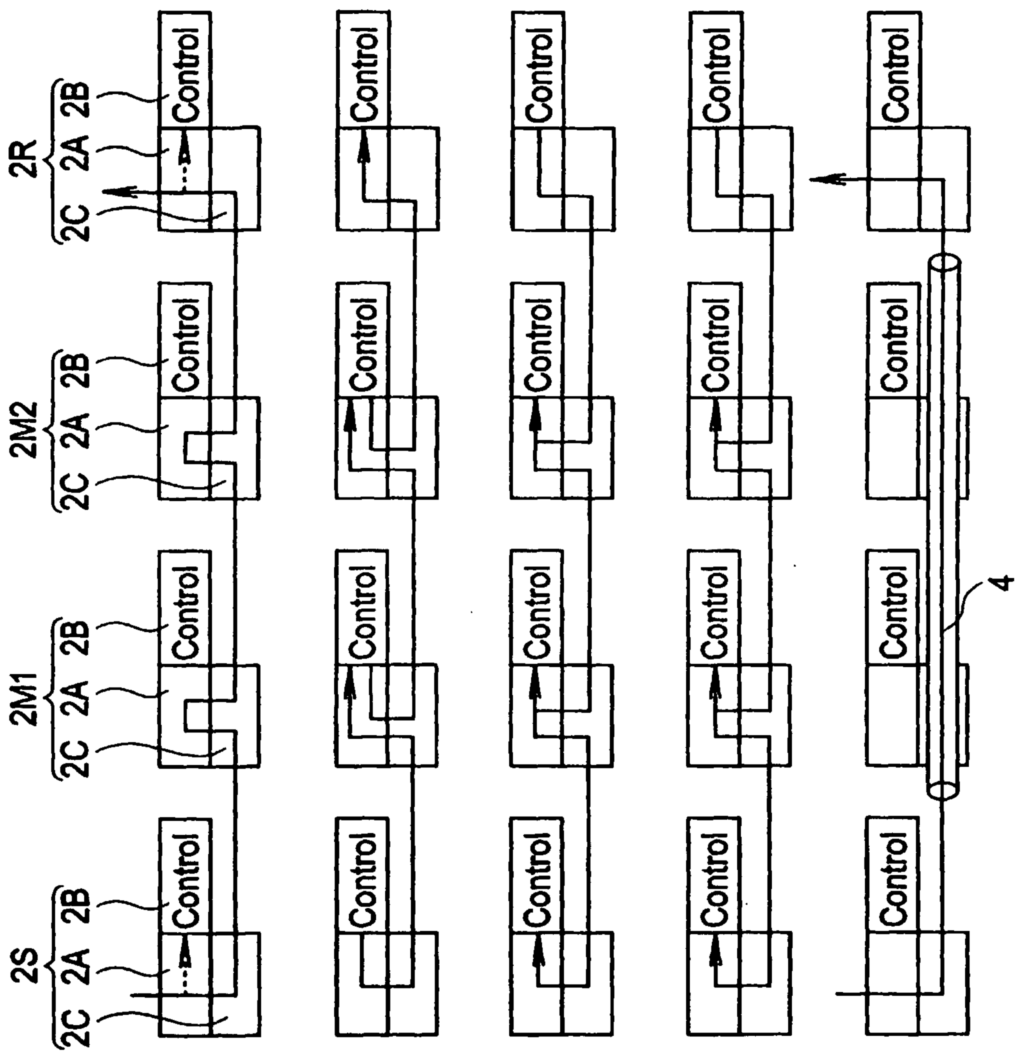


FIG.6(A)

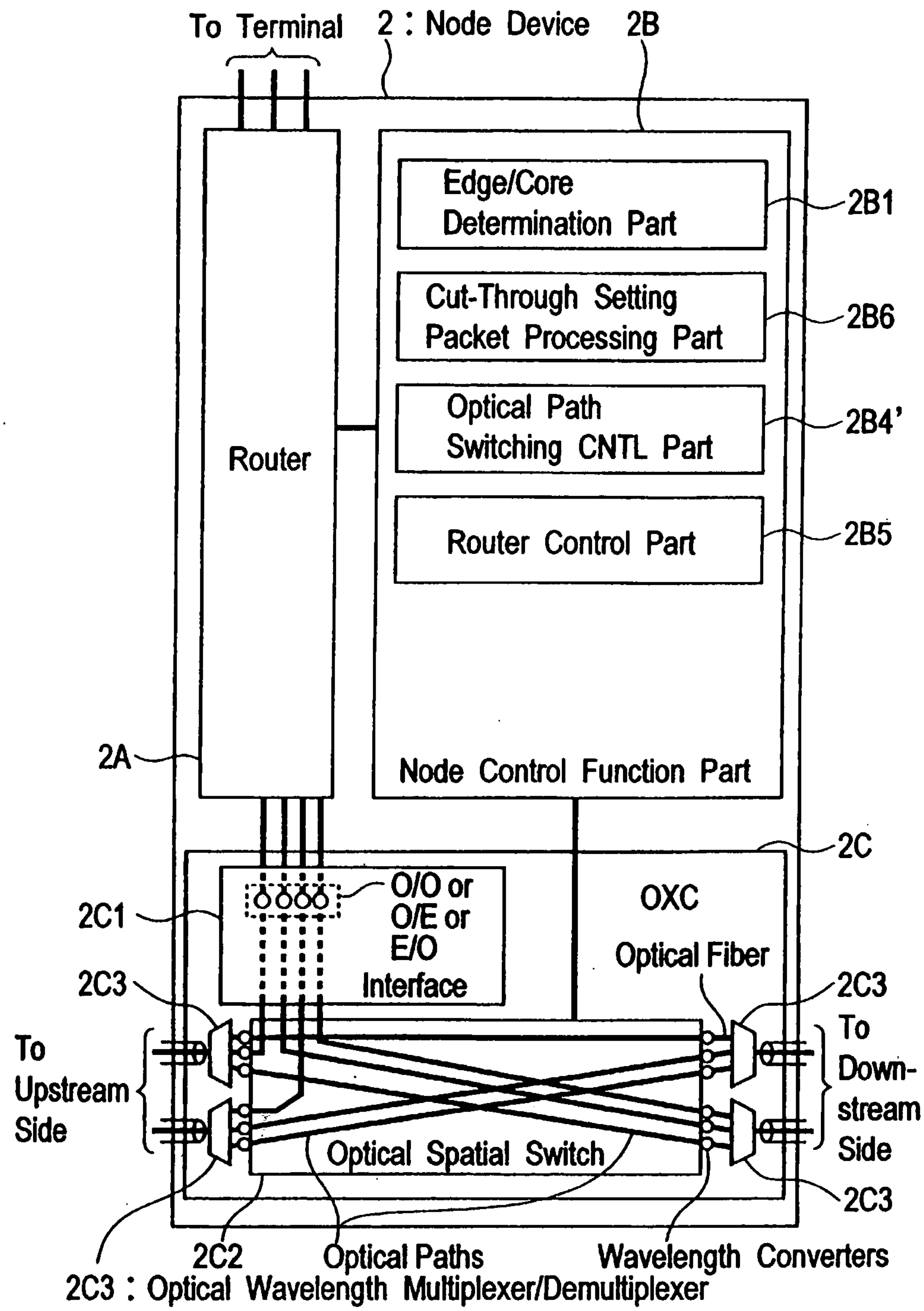
FIG.6(B)

FIG.6(C)

FIG.6(D)

FIG.6(E)

FIG. 7


To Terminal
2 : Node Device
2B
Edge/Core Determination Part
2B1
Cut-Through Setting Packet Processing Part
2B6
Optical Path Switching CNTL Part
2B4'
Router
Router Control Part
2B5
2A
Node Control Function Part
2C
2C1
O/O or O/E or E/O Interface
OXC
Optical Fiber
2C3
2C3
To Upstream Side
To Down-stream Side
Optical Spatial Switch
2C3
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

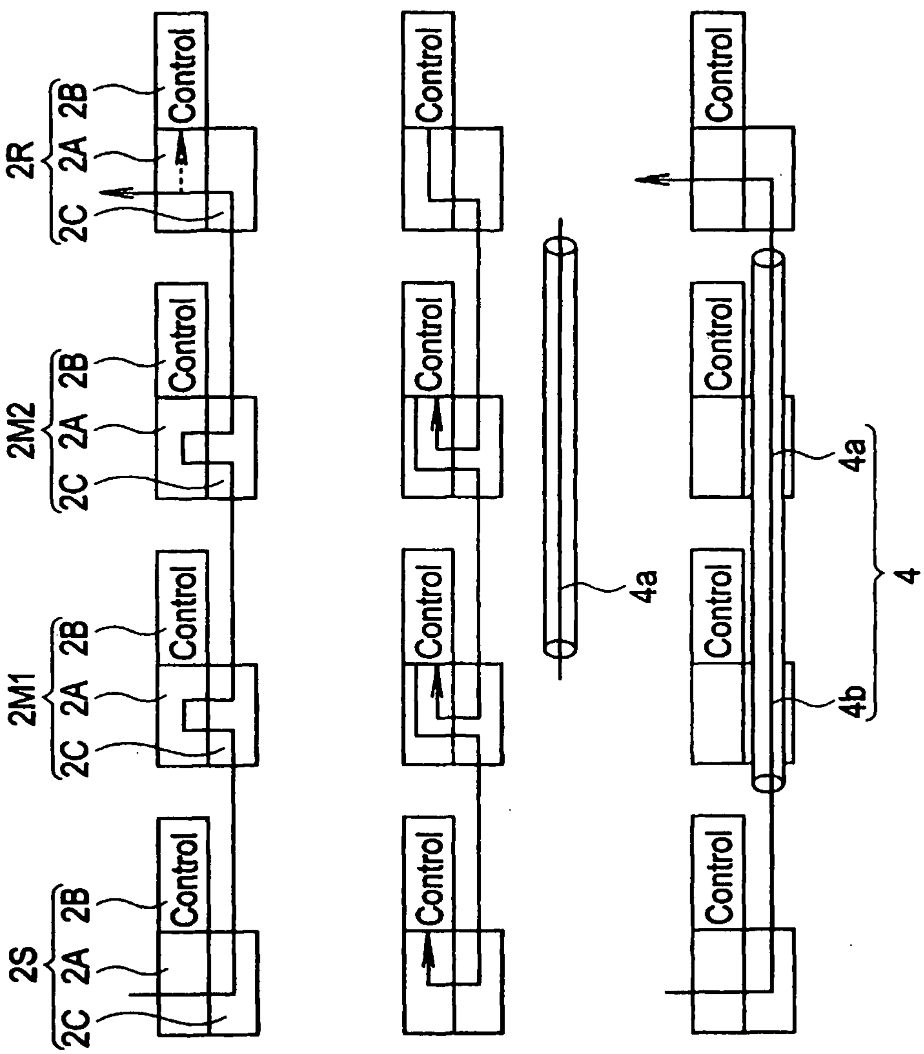


FIG.8(A)

FIG.8(B)

FIG.8(C)

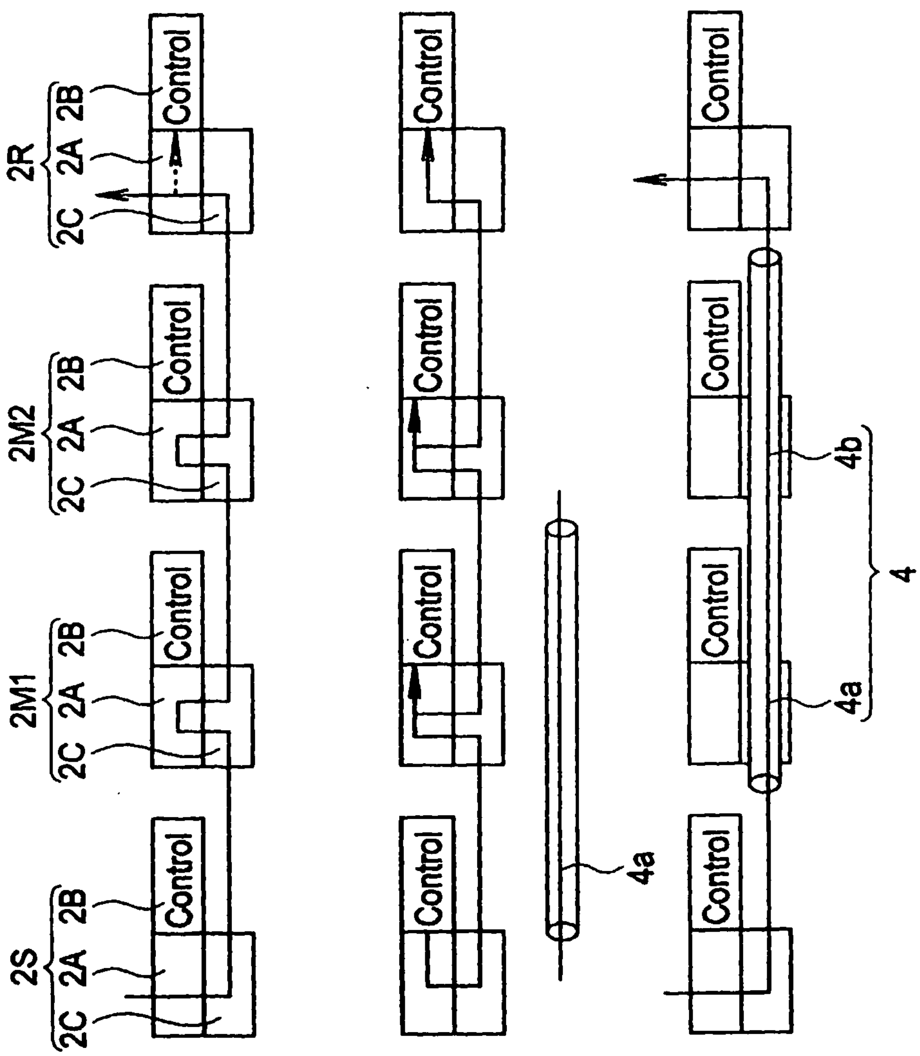


FIG.9(A)

FIG.9(B)

FIG.9(C)

FIG. 10

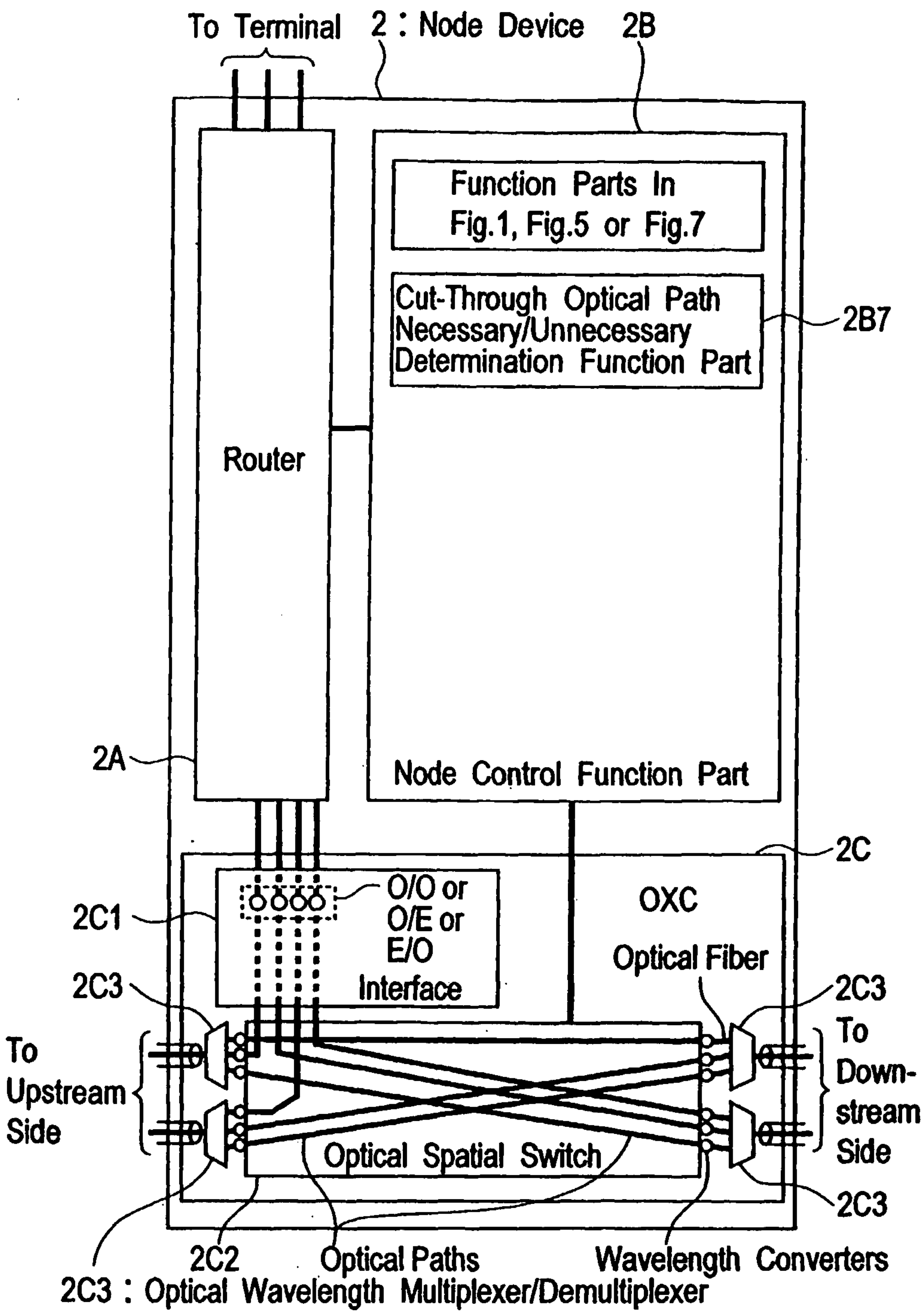
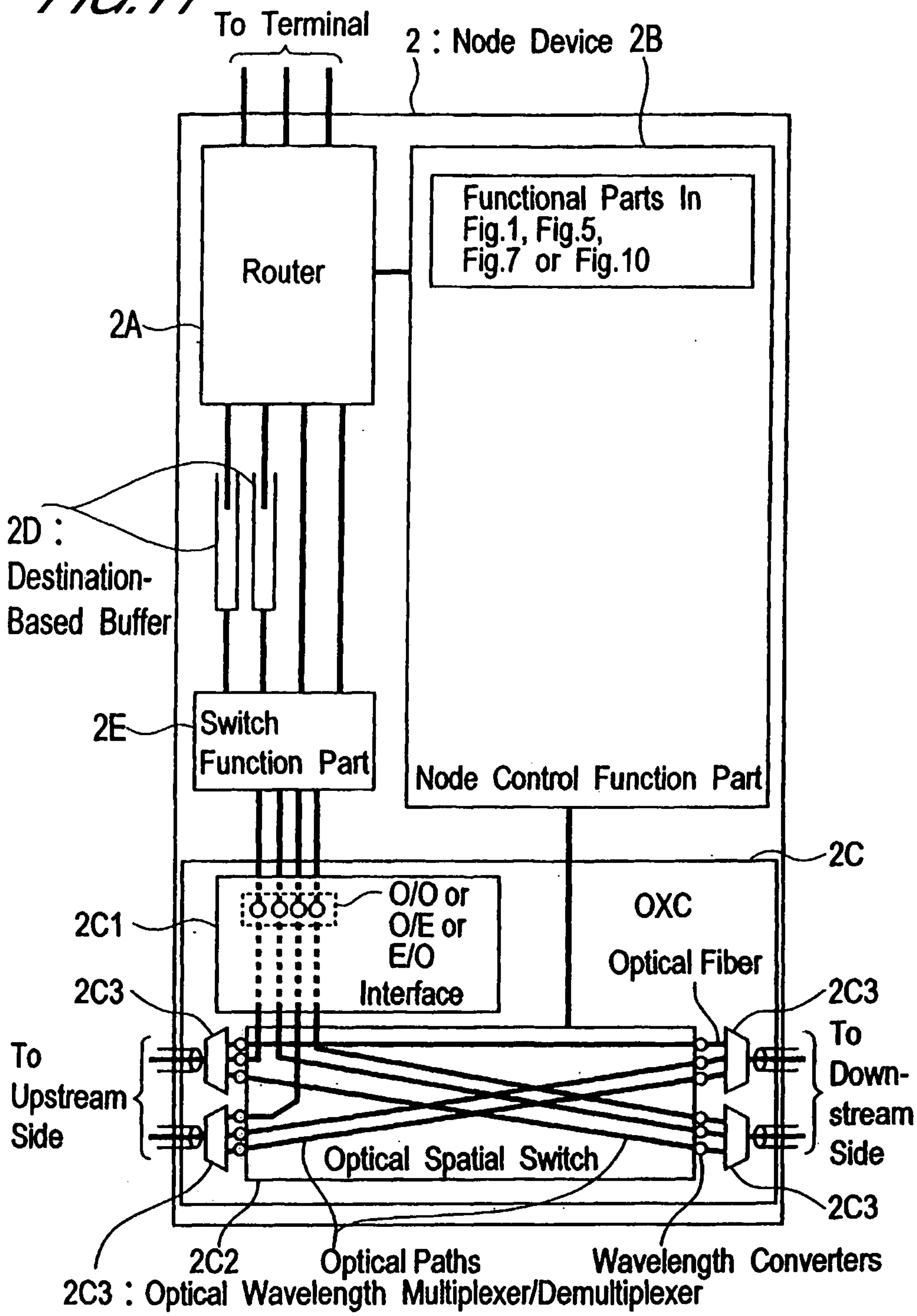

To Terminal
2 : Node Device
2B
Function Parts In
Fig.1, Fig.5 or Fig.7
Cut-Through Optical Path
Necessary/Unnecessary
Determination Function Part
2B7
Router
2A
Node Control Function Part
2C
2C1
O/O or
O/E or
E/O
Interface
OXC
Optical Fiber
2C3
2C3
To
Upstream
Side
To
Down-
stream
Side
Optical Spatial Switch
2C3
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

FIG. 11



To Terminal
2 : Node Device
2B
Functional Parts In Fig.1, Fig.5, Fig.7 or Fig.10
Router
2A
2D : Destination-Based Buffer
2E
Switch Function Part
Node Control Function Part
2C
2C1
O/O or O/E or E/O Interface
OXC
Optical Fiber
2C3
To Upstream Side
To Down-stream Side
Optical Spatial Switch
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

FIG. 12

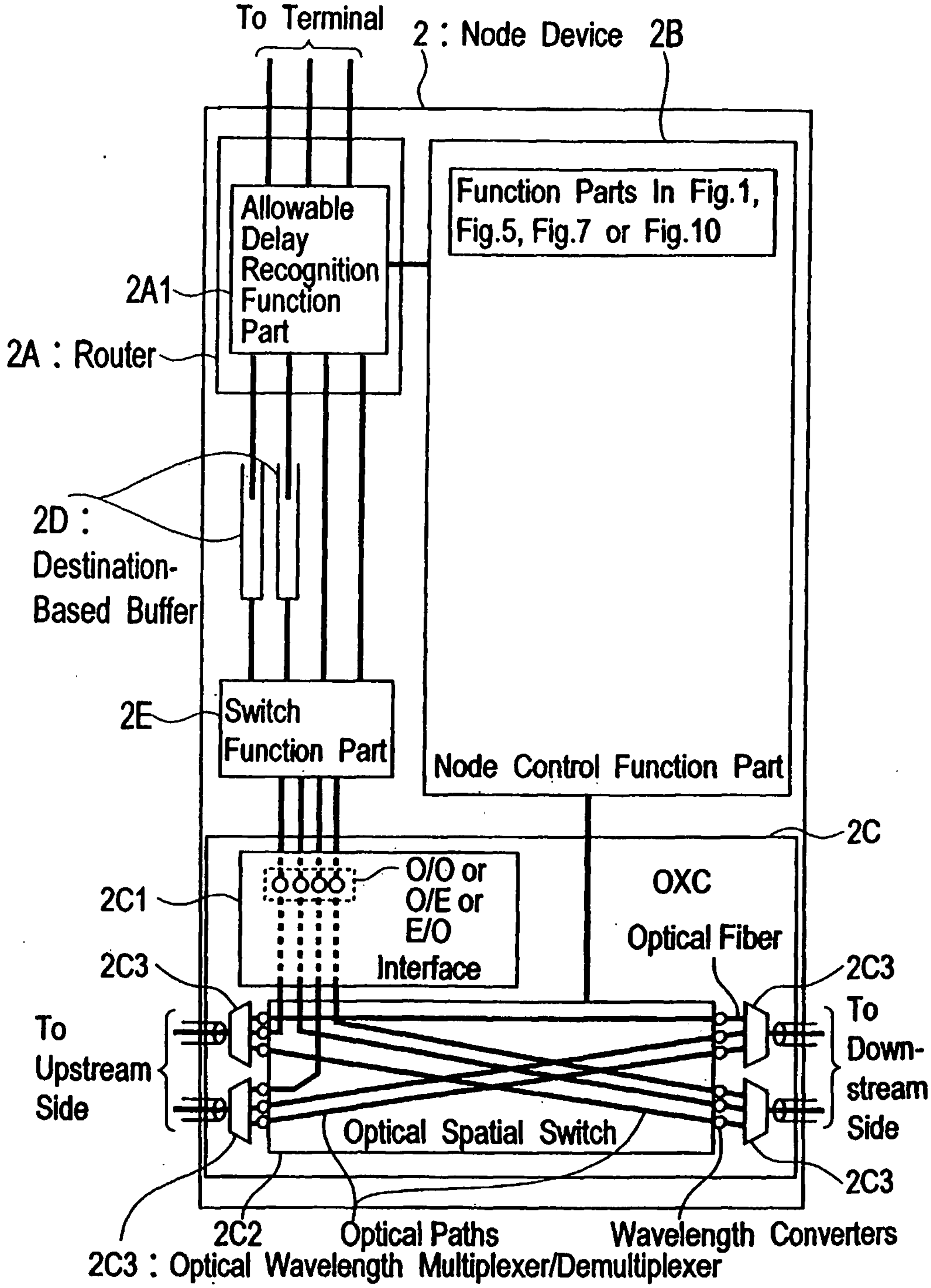

To Terminal
2 : Node Device
2B
Allowable Delay Recognition Function Part
2A1
2A : Router
Function Parts In Fig.1, Fig.5, Fig.7 or Fig.10
2D : Destination-Based Buffer
2E
Switch Function Part
Node Control Function Part
2C
2C1
O/O or O/E or E/O Interface
OXC
Optical Fiber
2C3
To Upstream Side
2C3
To Down-stream Side
Optical Spatial Switch
2C3
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

FIG. 13

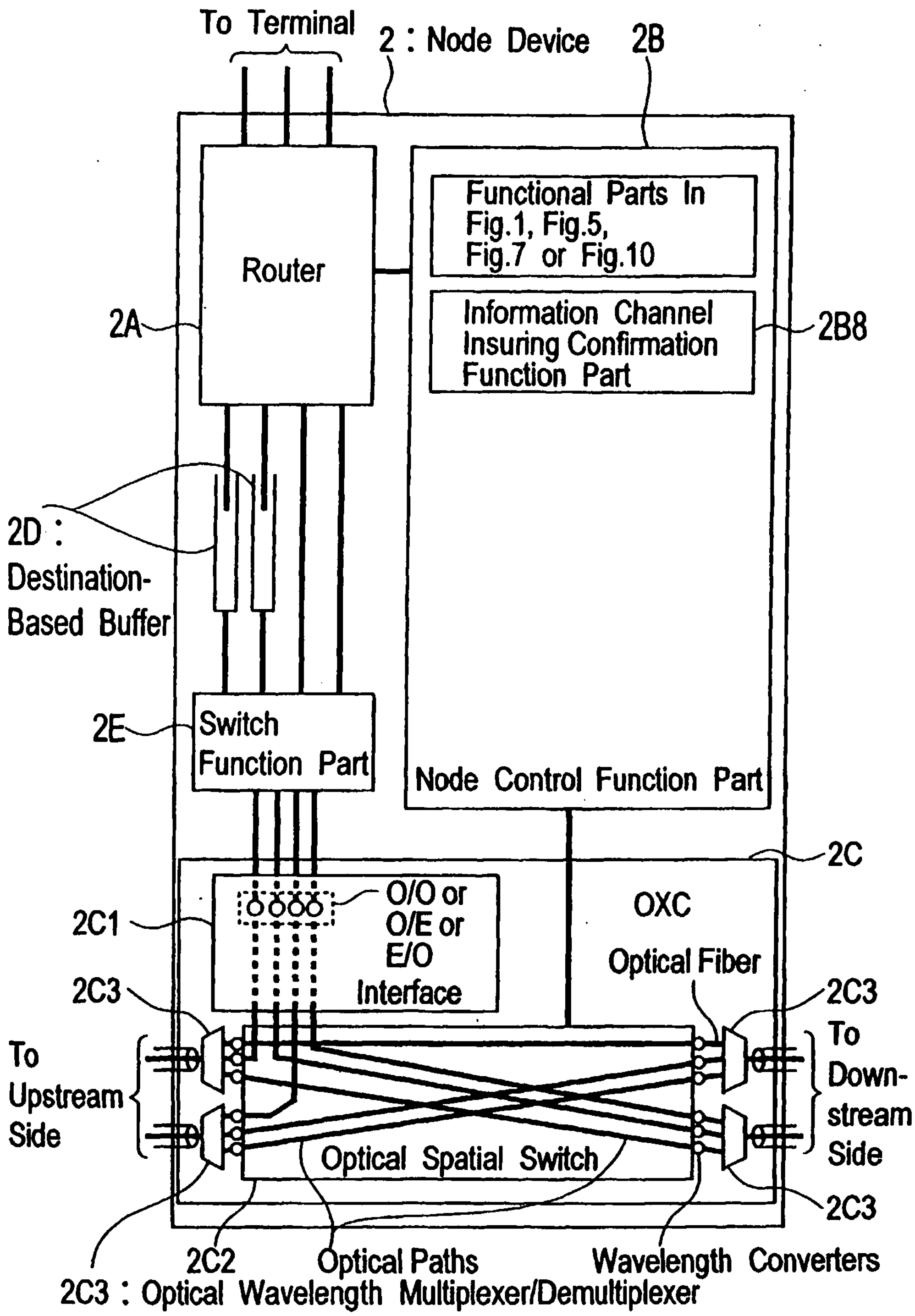
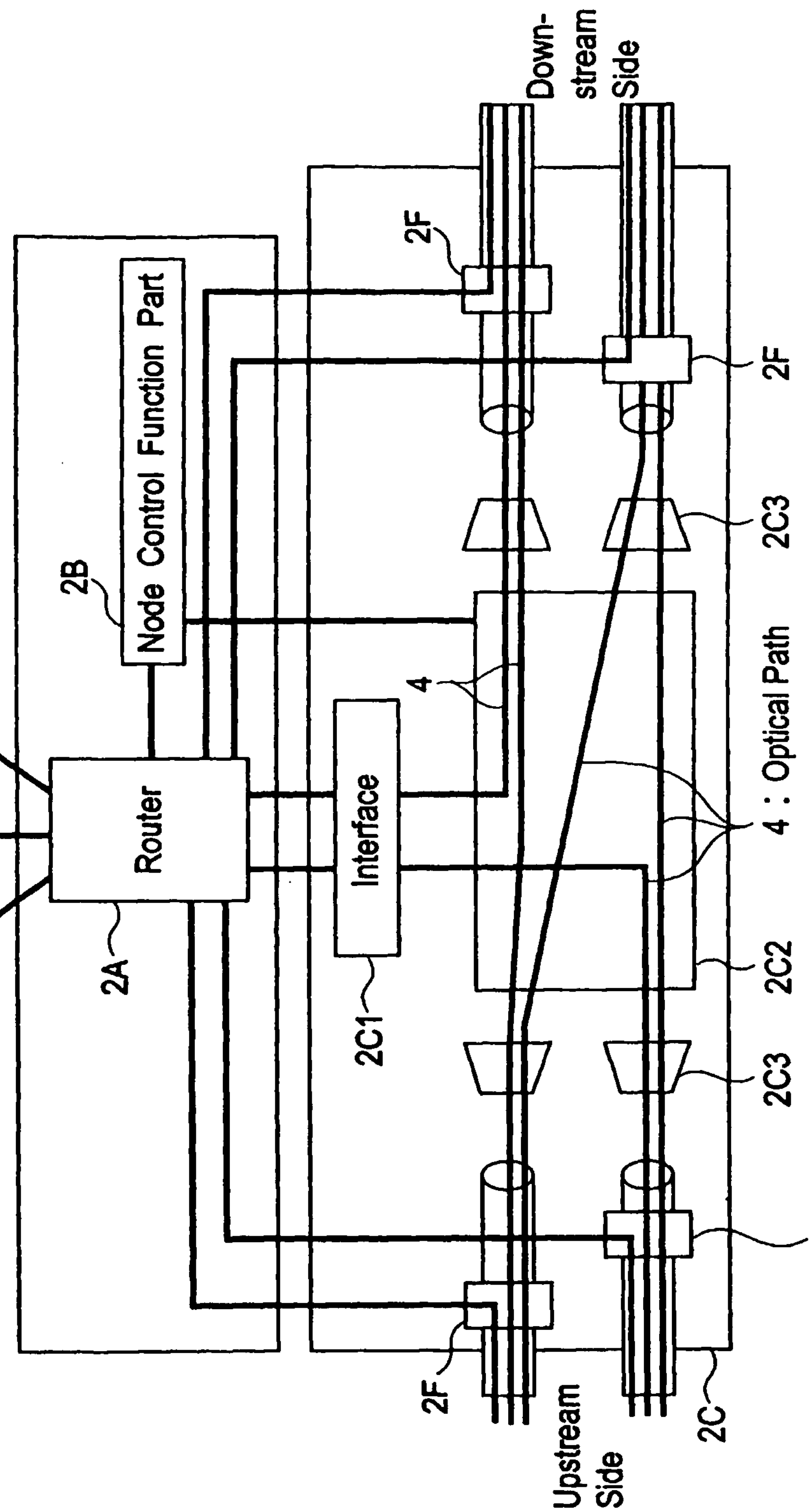

To Terminal
2 : Node Device
2B
Router
Functional Parts In Fig.1, Fig.5, Fig.7 or Fig.10
Information Channel Insuring Confirmation Function Part
2B8
2A
2D : Destination-Based Buffer
2E
Switch Function Part
Node Control Function Part
2C
2C1
O/O or O/E or E/O Interface
OXC
Optical Fiber
2C3
To Upstream Side
2C3
To Down-stream Side
Optical Spatial Switch
2C3
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

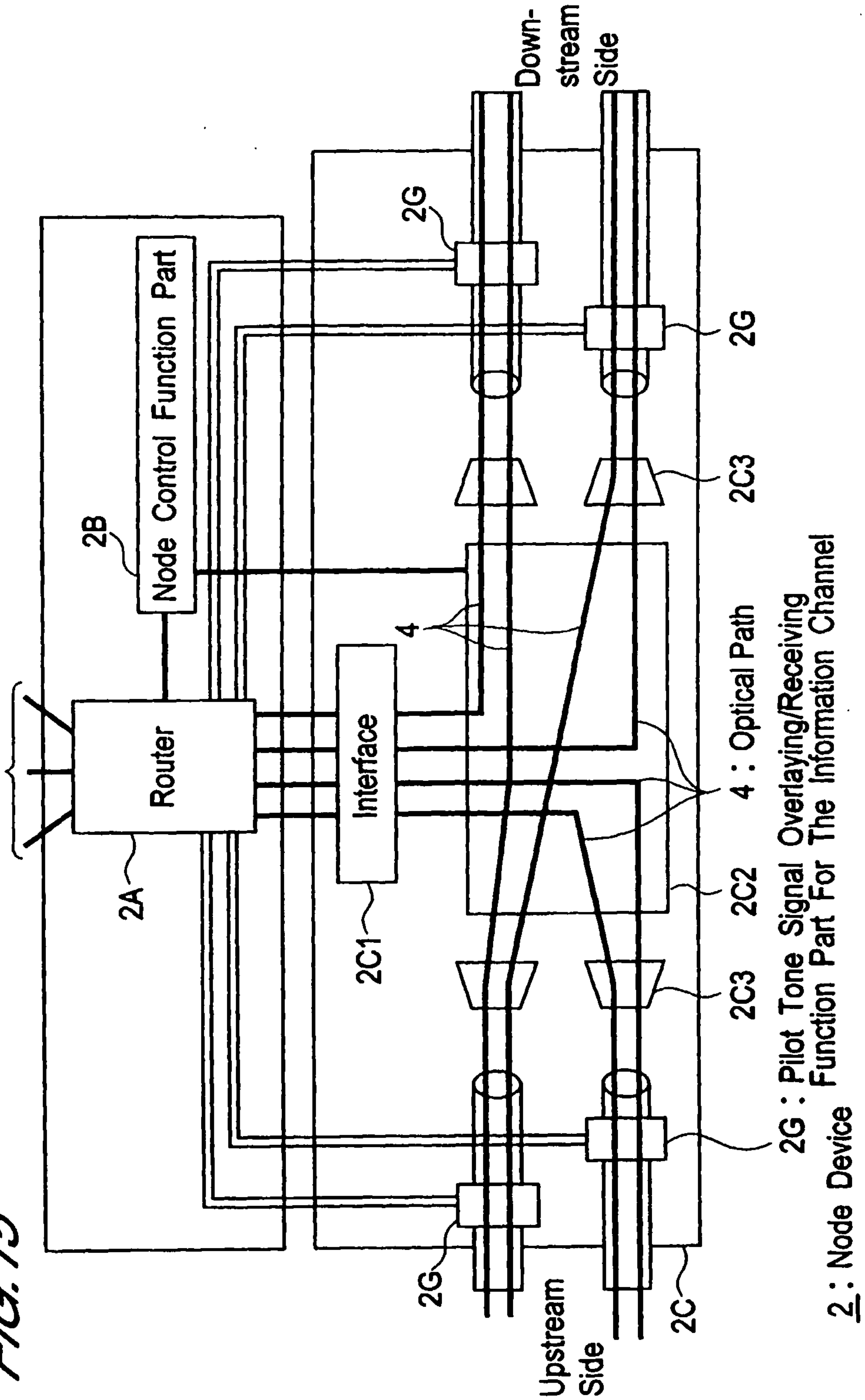
FIG. 14



2F : Optical Path Extraction/Insertion Part For The Information Channel

2 : Node Device

FIG. 15


To Terminal
Router
2A
2B
Node Control Function Part
Interface
2C1
2C2
2C3
2C3
2G
2G
2G
2G
4
Down-
stream
Side
Upstream
Side
2C
2 : Node Device
2G : Pilot Tone Signal Overlaying/Receiving Function Part For The Information Channel
4 : Optical Path

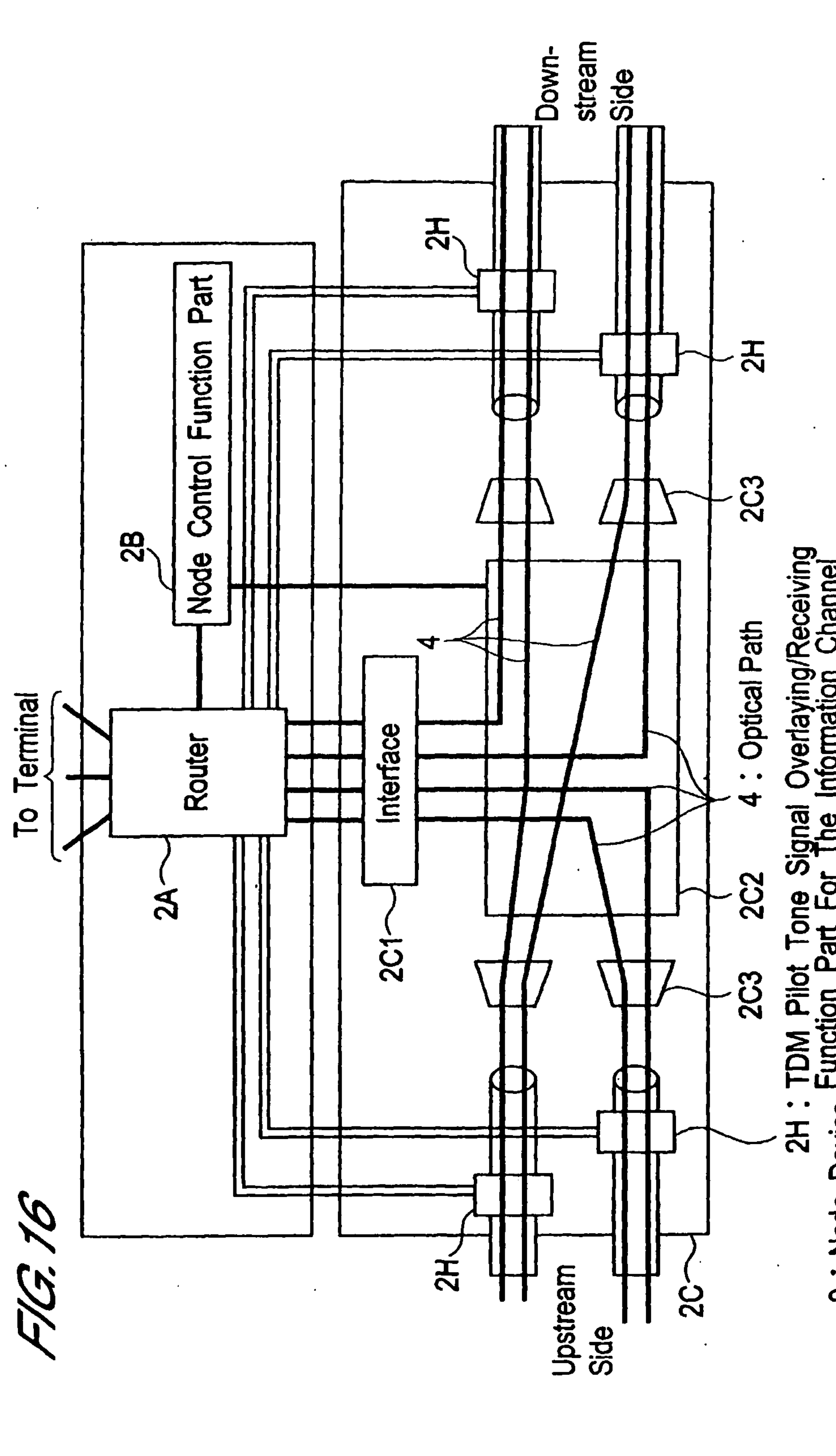
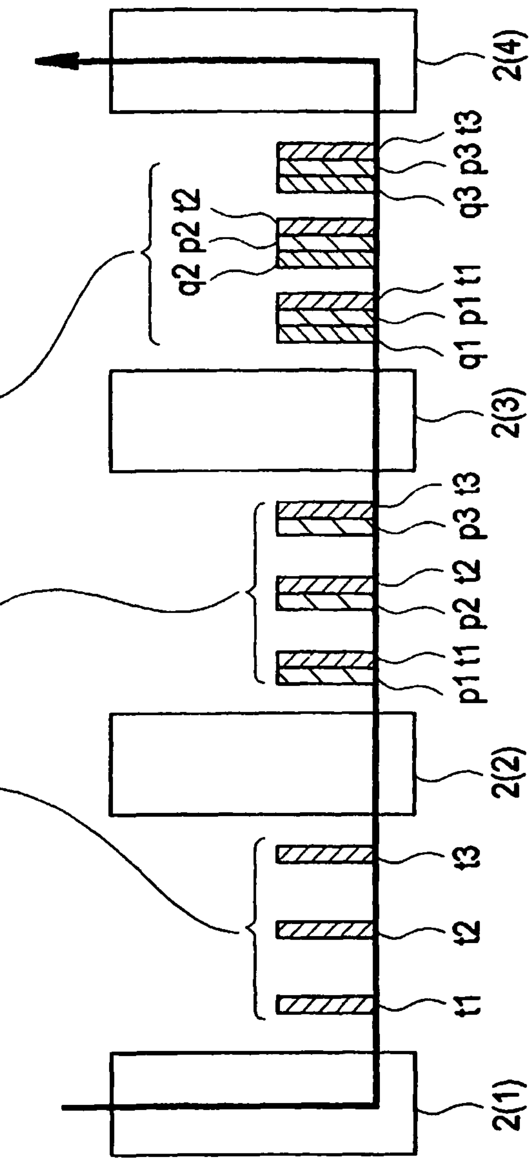

To Terminal
Router
2A
Node Control Function Part
2B
Interface
2C1
2C2
2C3
2C3
2H
2H
2H
2H
2C
4
4 : Optical Path
Upstream Side
Down-stream Side
2H : TDM Pilot Tone Signal Overlaying/Receiving Function Part For The Information Channel
2 : Node Device

FIG. 16

FIG. 17


Pilot Tone Signals To Be Overlaid
t1
t2
t3
p1 t1
p2 t2
p3 t3
q1 p1 t1
q2 p2 t2
q3 p3 t3
2(1)
2(2)
2(3)
2(4)

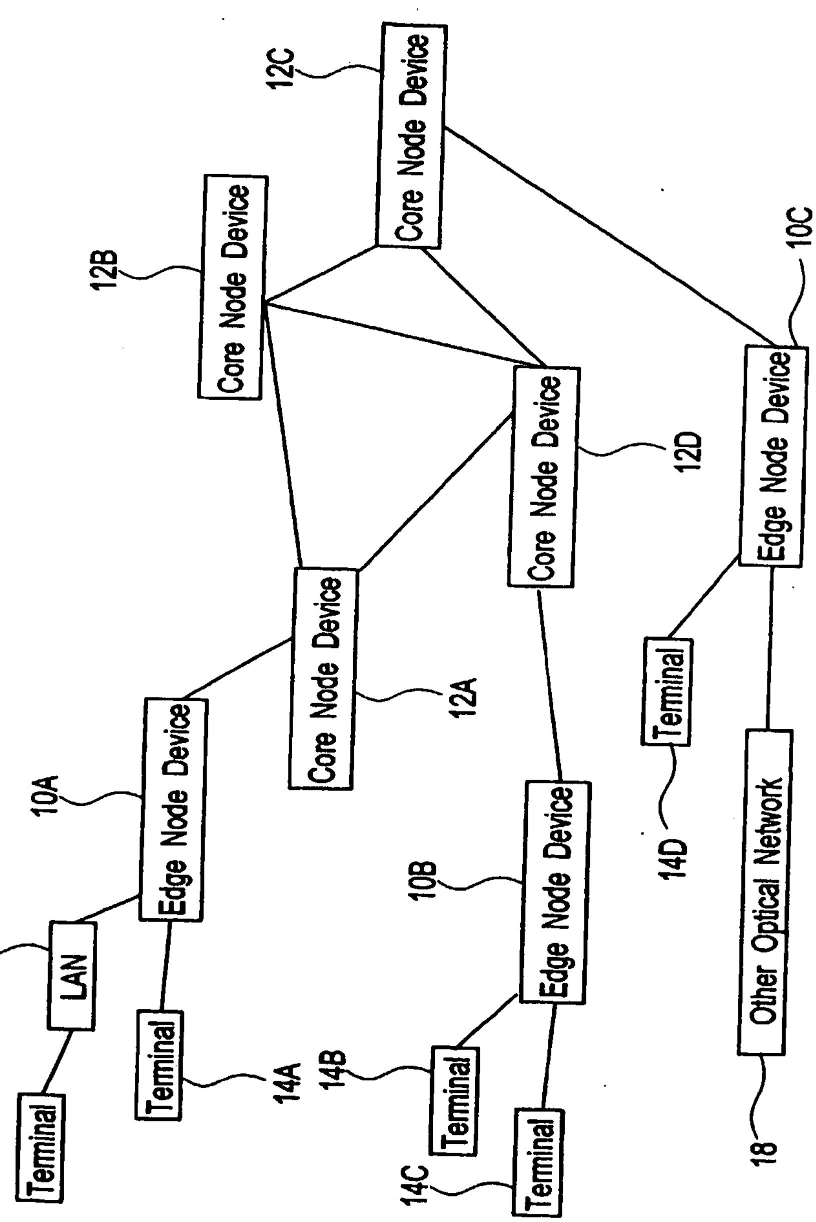

Core Node Device
12C
Core Node Device
12B
Core Node Device
12D
Edge Node Device
10C
Core Node Device
12A
Edge Node Device
10A
Edge Node Device
10B
Terminal
14D
Other Optical Network
18
LAN
16A
Terminal
Terminal
14A
Terminal
14B
Terminal
14C

FIG. 18

FIG. 19

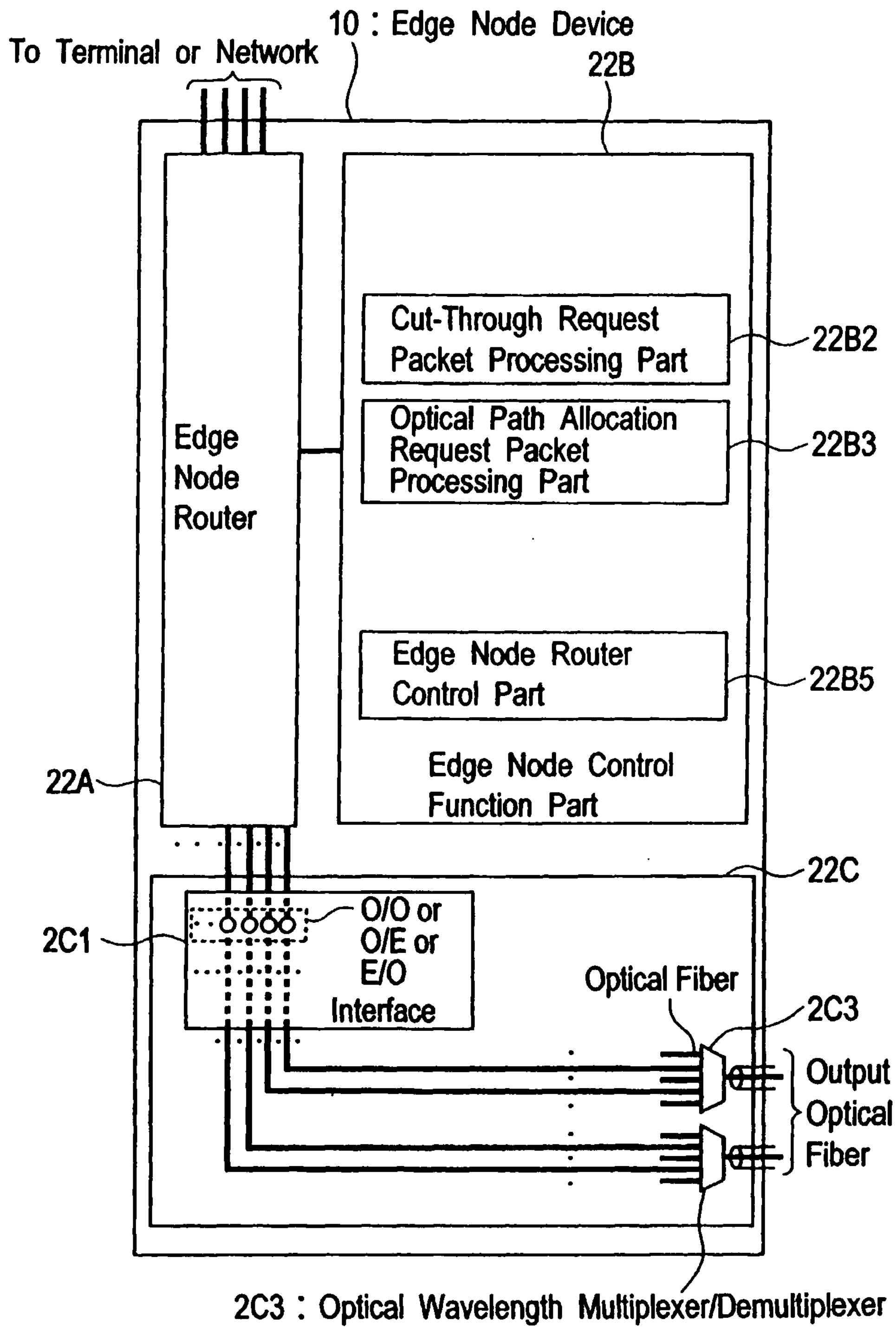
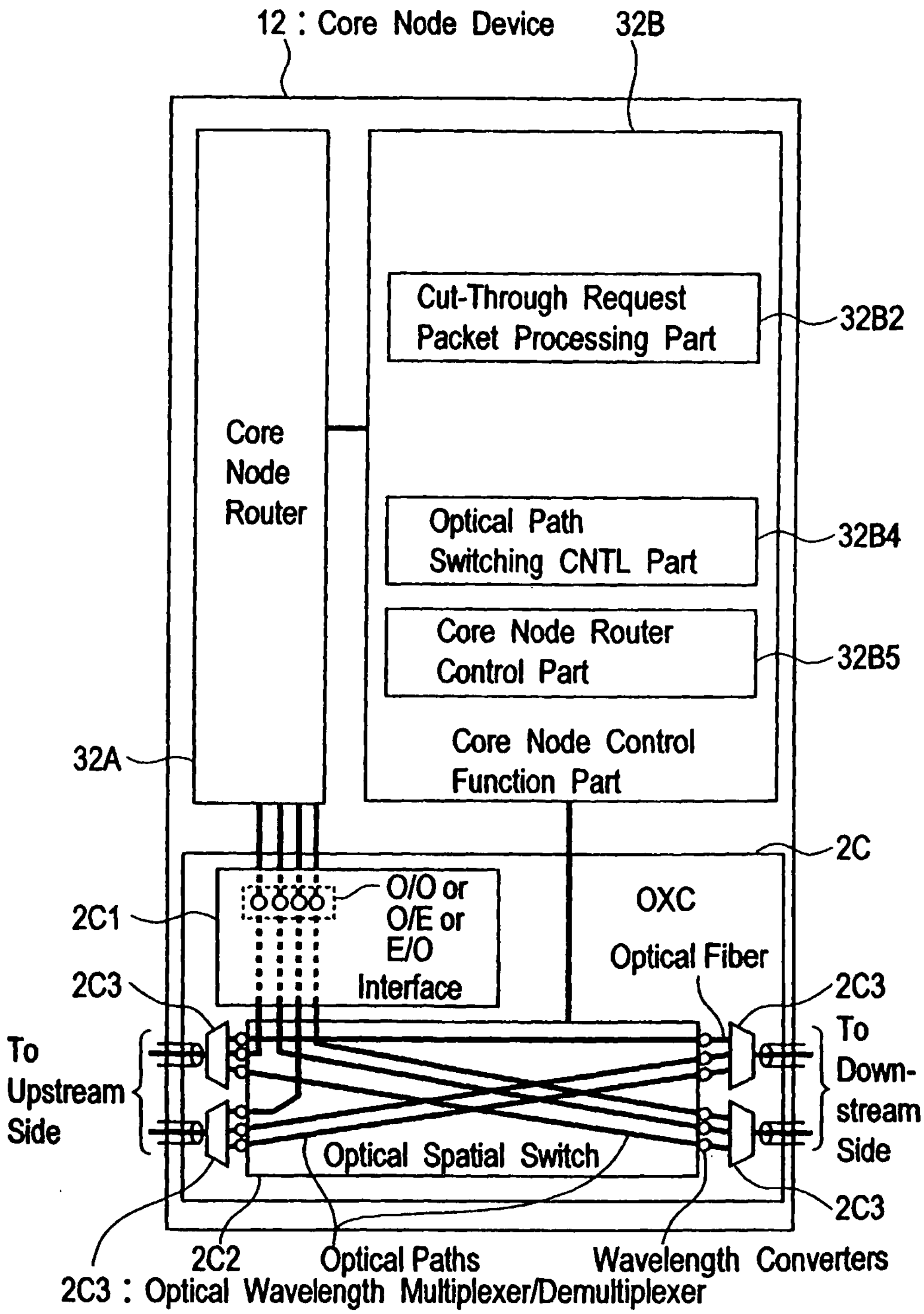

10 : Edge Node Device
To Terminal or Network
22B
Cut-Through Request Packet Processing Part
22B2
Optical Path Allocation Request Packet Processing Part
22B3
Edge Node Router
Edge Node Router Control Part
22B5
Edge Node Control Function Part
22A
22C
2C1
O/O or O/E or E/O Interface
Optical Fiber
2C3
Output Optical Fiber
2C3 : Optical Wavelength Multiplexer/Demultiplexer

FIG.20


12 : Core Node Device
32B
Cut-Through Request Packet Processing Part
32B2
Core Node Router
Optical Path Switching CNTL Part
32B4
Core Node Router Control Part
32B5
Core Node Control Function Part
32A
2C
2C1
O/O or O/E or E/O Interface
OXC
Optical Fiber
2C3
To Upstream Side
To Down-stream Side
Optical Spatial Switch
2C3
2C2
Optical Paths
Wavelength Converters
2C3 : Optical Wavelength Multiplexer/Demultiplexer

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(12) EUROPEAN PATENT APPLICATION

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H04Q 11/00

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MC NL PT SE TR
Designated Extension States:
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(54) Data channel reservation in optical burst-switched networks

(57) The present invention provides a system and method for reserving data channels in an optical burst-switched network. A data channel (or a multiple of data channels) along an optical path in an optical burst-switched network is reserved by first transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node. Next, the data channel reservation request is processed at all nodes along the optical path, including the reservation termination node. A data channel reservation acknowledgement is then transmitted from the reservation termination node to the electronic ingress edge router. Finally, the data channel path is reserved once an initial burst(s) which contains a reserve data channel bit reaches the reservation termination node.

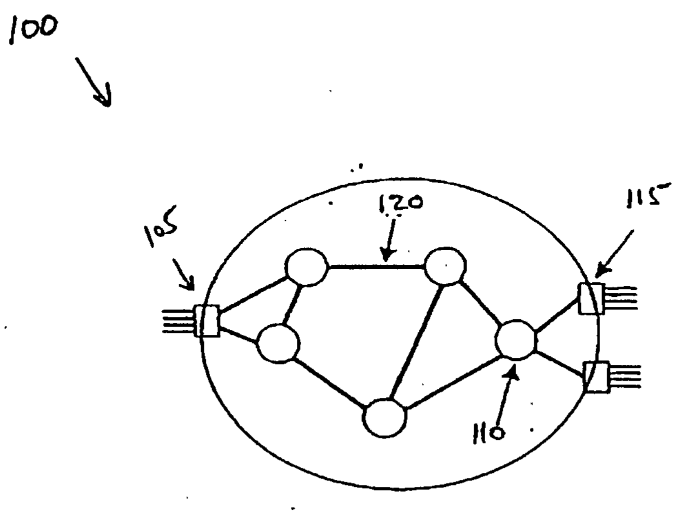

Figure 1: An optical burst-switched network.

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates generally to optical network systems, and more particularly to a system and method for providing data channel reservation in an optical burst-switched network.

BACKGROUND OF THE INVENTION

[0002] Data traffic over networks, particularly the internet, has increased dramatically over the past several years, and this trend will continue with the introduction of new services which require more bandwidth. The enlarged volume of internet traffic requires a network with high capacity routers capable of routing data packets with variable lengths. One option is the use of optical networks. However, current optical networks use only a small fraction of the bandwidth available on a single optical fiber.

[0003] The emergence of dense-wavelength division multiplexing (DWDM) technology has helped to overcome the bandwidth problem encountered by current optical networks. A single DWDM optical fiber has the capability of carrying as much as ten (10) terabits of data per second. Different approaches advocating the use of optical technology in place of electronics in switching systems has been proposed, however the limitations of optical component technology has largely limited optical switching to facility management applications. One approach called optical burst-switched networking attempts to make the best use of optical and electronic switching technologies. The electronics provides dynamic control of system resources, assigning individual user data bursts to channels of a DWDM fiber. Optical technology is used to switch the user data channels entirely in the optical domain.

[0004] One problem with switching user data channels entirely in the optical domain is that it is difficult to setup a data channel path across an optical burst-switched network without wasting network resources such as transmission and switching capacity. Each data channel within an optical path can range from ten (10) Gbps to forty (40) Gbps and the roundtrip delay of an optical path is very long when using conventional signaling approaches. Thus, setting up an optical path with bandwidth of one or more data channels in an optical burst-switched network takes a long time and wastes a huge amount of bandwidth. If the connection time is not sufficiently long, the bandwidth wasted may not be well justified.

[0005] Another problem with optical burst-switched networks relates to data channel scheduling. Schedulers within switch control units of core routers in the optical burst-switched network are responsible for scheduling burst payloads and their corresponding burst header packets on data channel groups (DCG) and control channel groups (CCG), respectively. A burst header packet has to be processed in the switch control unit as quickly as possible, thus the scheduling algorithm must be simple and fast.

[0006] One prior art scheduling algorithm is the Latest Available Unscheduled Channel (LAUC) algorithm , also known as the Horizon algorithm. In the LAUC algorithm, only one value, the future available/unscheduled time, is remembered for each data channel. However, the LAUC algorithm results in high burst loss ratio and thus low channel utilization due to the gaps/voids between bursts. Other more sophisticated scheduling algorithms usually lead to less burst loss ratio, but their implementation are very difficult since the scheduler has to work at a very high speed (e.g., about 100 nanoseconds per burst). Thus, a simple and fast scheduling algorithm is needed to reduce the burden of schedulers in optical burst-switched networks and to improve the performance of data channel scheduling.

SUMMARY OF THE INVENTION

[0007] The present invention provides an optical burst-switched network that substantially eliminates or reduces disadvantages and problems associated with previously developed optical burst-switched networks used for switching data channels.

[0008] More specifically, the present invention provides a system and method for reserving data channels in an optical burst-switched network. A data channel along an optical path in an optical burst-switched network is reserved by first transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node. Next, the data channel reservation request is processed at the reservation termination node. A data channel reservation acknowledgement is then transmitted from the reservation termination node to the electronic ingress edge router. Finally, the data channel path is reserved once an initial burst(s) which contains a reserve data channel bit reaches the reservation termination node.

[0009] The present invention provides an important technical advantage by providing a mechanism to use "cross connect" in the optical burst-switched network whenever possible without losing the efficiency and flexibility of burst switching.

[0010] The present invention provides another technical advantage by avoiding unnecessary hop-by-hop burst scheduling.

[0011] The present invention provides yet another technical advantage by reducing'the load on schedulers of switch control units in optical core routers.

[0012] The present invention provides yet another technical advantage by reducing the gaps/voids between bursts transmitted on the reserved data channels, which in turn increases the data channel utilization.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings in which like reference numerals indicate like features and wherein:

FIGURE 1 shows an optical burst-switched network according to the present invention;
FIGURE 2 shows a more detailed example of an optical burst-switched network according to the present invention;
FIGURE 3 shows a functional block diagram of an electronic edge router according to the present invention;
FIGURE 4 shows one example of the forwarding information base at an electronic edge router according to the present invention;
FIGURE 5 shows a functional block diagram of an optical core router according to the present invention;
FIGURE 6 shows one example of the label information base at an optical core router according to the present invention;
FIGURE 7 shows an example depicting the data channel path set up according to the present invention;
FIGURE 8 shows an example of the channel information base at optical core router C4;
FIGURE 9 shows an example of the channel information base at optical core router C1; and
FIGURE 10 shows an example depicting the threshold of a new queue for a reserved data channel.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Preferred embodiments of the present invention are illustrated in the FIGUREs, like numerals being used to refer to like and corresponding parts of the various drawings.

[0015] FIGURE 1 shows one example of an optical burst-switched network 100. The optical burst switched network includes multiple electronic ingress edge routers 105, multiple optical core routers 110, multiple electronic egress edge routers 115, and multiple dense-wavelength division multiplexing (DWDM) optical links 120. The DWDM optical links 120 connect the electronic ingress edge routers 105, the optical core routers 110, and the electronic egress edge routers 115 together. The electronic ingress edge routers 105 and the electronic egress edge routers 115 perform burst assembly/disassembly functions and serve as legacy interfaces between the optical burst-switched network 100 and conventional electronic routers. Note that, although electronic ingress edge router and electronic egress edge router are logically distinguished in FIGURE 1, both functions are often physically combined in a single physical edge router device.

[0016] A burst, the basic data block to be transferred through the optical burst-switched network, is a collection of data packets which have the same destination (network egress address) or destinations and other attributes such as quality of service (QoS) requirements. A burst consists of a burst header packet (BHP) and a burst payload. The format of the burst header packet may consists of an Internet protocol (IP) header (e.g., IPv4, IPv6) or a multi-protocol label switching (MPLS) shim header if MPLS is used or both, together with the optical burst switching specific information which will be used by switch control units to route bursts and by electronic egress edge routers 115 to receive bursts.

[0017] FIGURE 2 shows a more detailed example of the optical burst-switched network 100. Each DWDM optical link 120 can have many data channels 205. Each data channel 205 carries a single wavelength λ Without loss of generality, in FIGURE 2, assume here that all data channels 205 have the same transmission capacity which equals R bits per second (bps). Packets are assembled into bursts at electronic ingress edge routers 105 according to a burst assembly mechanism. The bursts are then forwarded at layer 3 or switched at layer 2 (if a MPLS type label switching mechanism is used) through the optical burst-switched network 100 to their electronic egress edge routers 115. A burst flow can be defined as a set of bursts which have the same electronic ingress edge router 105, follow the same path, and are destined to the same reservation termination node (RTN). The RTN can either be an electronic egress edge router 115 or an optical core router 110. A more strict definition of a burst flow requires that the bursts have the same or similar attributes like quality of service (QOS).

[0018] FIGURE 3 shows a functional block diagram of an electronic edge router 300 according to the present invention. The electronic edge router 300 can consist of both an electronic ingress edge router 105 and an electronic egress edge router 115. The electronic edge router 300 includes a routing processor 305, a fiber and channel database 310, a signaling processor 315, a data channel path (DCP) management module 320, a burst flow monitoring module 325, a scheduler 330, a routing information base (RIB) 335, a forwarding information base (FIB) 340, and input and output ports 355. The scheduler 330 contains a channel information base (CIB) 350.

[0019] The routing processor 305 transmits to and receives network information from neighboring communication devices through the input and output ports 355. The neighboring communication devices can be another electronic edge router 300, optical core router 110, or other communication devices. The routing processor 305 runs the routing protocols (some are optical burst switching specific), exchanges information with neighboring communication devices, and updates the RIB

335 and FIB 340. The RIB 335 contains all the necessary routing information for the network. The RIB information constantly changes and is updated with current network routing information through the routing processor 305. The FIB 340 contains next hop (i.e. outbound DCG) information for arriving bursts. The next hop could either be an electronic egress edge router 115 or an optical core router 110. The FIB 340 is created and maintained by the routing processor 305 using the RIB 335.

[0020] When using a label-swapping technique like the MPLS, an additional column is added to the FIB 340 which is used to assign a label for each outgoing burst. An example of the FIB 340 is shown in FIGURE 4. Note that only relevant information to the current invention is shown in FIGURE 4, which is also the case for other figures. The fiber and channel database 310 receives and stores network information from the routing processor 305 and the signaling processor 315. This network information includes (1) the inbound and outbound fibers and the wavelengths within each fiber; (2) the inbound and outbound data channel groups, control channel groups, and channels within each group; (3) the mapping of data channel groups, control channel groups, and channels within each group to the physical fibers and wavelengths; and (4) the status of each inbound/outbound data channel 205. The data channels 205 can be in one of three possible states. The three states are the unreserved state, the reservation in progress state, and the reserved state. When a data channel 205 is in the unreserved state, the burst flow is being scheduled on the data channel 205 in the normal way. When a data channel 205 is in the reservation in progress state, the data channel 205 is reserved, but not committed. This means that the data channel 205 will still be used in the normal fashion (i.e., as an unreserved data channel). Thus, no data channel 205 bandwidth is wasted. A "0" is placed in the CIB 350 under the status field to represent the reservation in progress state. When a data channel 205 is in the reserved state, this means that the data channel 205 is committed and bursts cannot be scheduled on the reserved data channel 205 in the normal fashion.

[0021] The signaling processor 315 also transmits to and receives network information from neighboring communication devices through input and output ports 355. The burst flow monitoring module 325 monitors the burst flow to optical core routers 110 and electronic egress edge routers 115 and informs the signaling processor 315 when the average bit rate of a flow of bursts exceeds or drops below a given threshold. The threshold is defined here as a bit rate which is no less than a data channel bit rate. If the bit rate of a flow of bursts exceeds the given threshold, the data channel 205 can be reserved. If the bit rate of a flow of bursts drops below the given threshold, part of the reserved data channel 205 is not being used, thus reservation of the reserved data channel 205 will be terminated.

[0022] The DCP management module 320 transmits and receives information to and from the signaling processor 315. The purpose of the DCP management module 320 is to keep track of all the data channel 205 paths either already reserved or in the process of being reserved. The scheduler 330 also transmits and receives information to and from the signaling processor 315. The purpose of the scheduler 330 is to schedule the transmission of bursts and their associated burst header packets on data channel groups and control channel groups, respectively. There can be a scheduler 330 for a pair of data channel group and control channel group, or a set of data/control channel group pairs. Without loss of generality, FIGURE 3 shows one scheduler 330 per data/control channel group pair.

[0023] The channel information base 350 in the scheduler 330 contains a subset of the fiber and channel database 310. This subset can include all inbound data channel groups, the outbound data channel groups and control channel groups, and the mapping to (physical) fibers and wavelengths. The outbound data channels 205 are divided into two subgroups. The two subgroups include (1) unreserved and reservation in progress data channels and (2) reserved data channels. Data channels 205 which are in the reservation in progress state operate exactly the same as data channels which are in the unreserved state. The use of reservation in progress outbound data channels is the same as unreserved outbound data channels. In addition, the channel information base 350 maintains a table for the reserved inbound and outbound data channels 205.

[0024] FIGURE 5 shows a functional block diagram of an optical core router 110 according to the present invention. The optical core router 110 includes a routing processor 505, a fiber and channel database 510, a signaling processor 515, a data channel path (DCP) management module 520, a routing information base (RIB) 525, a switch control unit (SCU) 530 and input and output ports 555. The SCU includes a forwarding information base (FIB) 540, a label information base (LIB) 545, and a scheduler 535. The scheduler 530 contains a channel information base (CIB) 550.

[0025] The routing processor 505 transmits to and receives network information from neighboring communication devices through the input and output ports 555. The neighboring communication devices can be another electronic edge router 300, optical core router 110, or other communication devices. The routing processor 505 runs the routing protocols (some are optical burst switching specific), exchanges information with neighboring communication devices, and updates the RIB 525, FIB 540, and LIB 545. The RIB 525 contains all the necessary routing information for the network. The routing information base constantly changes and is updated with current network routing information through the routing processor 505. The FIB 540 contains next hop (i.e. outbound DCG) information for arriving bursts. The next hop could either be an electronic egress edge router 115 or an optical core router 110. The FIB 540 is cre-

ated and maintained by the routing processor 505 using the RIB 525. The LIB 545 is established when a label-swapping technique like the MPLS is used to switch bursts at layer 2. Shown in FIGURE 6 is an example of the LIB 545.

[0026] The fiber and channel database 510 receives and stores network information from the routing processor 505 and the signaling processor 515. This network information includes (1) the inbound and outbound fibers and the wavelengths within each fiber; (2) the inbound and outbound data channel groups, control channel groups, and channels within each group; (3) the mapping of data channel groups, control channel groups, and channels within each group to the physical fibers and wavelengths; and (4) the status of each inbound/outbound data channel 205. Again, the data channels 205 can be in one of three possible states. The three states are the unreserved state, the reservation in progress state, and the reserved state. When a data channel 205 is in the unreserved state, the burst flow is being scheduled on a data channel 205 in the normal way. When a data channel 205 is in the reservation in progress state, the data channel 205 is reserved, but not committed. This means that the data channel 205 will still be used in the normal fashion (i.e., as an unreserved data channel) Thus, no data channel 205 bandwidth is wasted. A "0" is placed in the CIB 550 under the status field to represent the reservation in progress state. When a data channel 205 is in the reserved state, this means that the data channel 205 is committed and bursts cannot be scheduled on the reserved data channel 205 in the normal fashion.

[0027] The signaling processor 515 also transmits to and receives network information from neighboring communication devices through input and output ports 555. The DCP management module 520 transmits and receives information to and from the signaling processor 515. The purpose of the DCP management module 520 is to keep track of all the data channel paths either already reserved or in the process of being reserved. The scheduler 535 also transmits and receives information to and from the signaling processor 515. The purpose of the scheduler 535 is to schedule the transmission of bursts and their associated burst header packets on data channel groups and control channel groups, respectively. The scheduler 535 at the optical core router 110 schedules the switching of bursts from the inbound data channel groups to the outbound data channel groups and the transmission of the associated burst header packets on the outbound control channel groups. There can be a scheduler 535 for a pair of data channel group and control channel group, or a set of data/control channel group pairs. Without loss of generality, FIGURE 5 shows one scheduler 535 per data/control channel group pair.

[0028] The channel information base 550 in the scheduler 535 contains a subset of the fiber and channel database 510. This subset can include all inbound data channel groups, the outbound data channel groups and control channel groups, and the mapping to (physical) fibers and wavelengths. The outbound data channels are divided into two subgroups. The two subgroups include (1) unreserved and reservation in progress data channels and (2) reserved data channels. Data channels 205 which are in the reservation in progress state operate exactly the same as data channels which are in the unreserved state. In addition, the channel information base 550 maintains a table for the reserved inbound and outbound data channels 205 (see FIGURE 9).

[0029] Referring back to FIGURE 2, a burst can only be transmitted at the bit rate of a data channel 205, although the total transmission capacity of a DWDM optical link 120 is much larger than that of a single data channel 205. If the average bit rate of a flow of bursts from an electronic ingress edge router 105 to an electronic egress edge router 115 is identified to be larger than a data channel rate, at least one data channel 205 could be reserved on the path between the electronic ingress edge router 105 to the electronic egress edge router 115, either via default route or explicit route. By doing so, gaps/voids could be largely eliminated on the reserved data channels 205 along the path right from the electronic ingress edge router 105. Furthermore, the load of the corresponding schedulers is reduced as no scheduling needs to be done for a reserved data channel 205, except updating the data channel 205 unscheduled (or future available) time. Traffic flow that cannot be accommodated by the reserved data channel 205 path can be forwarded hop-by-hop to the electronic egress edge router 115 as before. This methodology is not limited to an electronic ingress edge router 105 and electrocnic egress edge router 115 pair. It can also be extended to any pair of electronic ingress edge router 105 and optical core routers 110 in the optical burst-switched network 100.

[0030] In FIGURE 2, assume that the average bit rate X of a burst flow from electronic ingress edge router E_1 to a RTN, say optical core router C_4, is detected by the burst flow monitoring module 325 to be $R+\Delta$ bps where $\Delta \geq 0$. The burst flow monitoring module 325 will first notify the signaling processor 315. The electronic ingress edge router E_1 may then decide to reserve a data channel 205 along a path for the flow so that a large portion of the traffic ($=R/(R+\Delta)$) will be transported via the reserved data channel 205. It is expected that gaps/voids on the reserved data channel 205 can be substantially reduced or even largely eliminated if Δ is sufficiently large or the fluctuation of the burst flow is small. To reserve a data channel 205 path, the signaling processor 315 first consults with the routing processor 305 for a route from the electronic ingress edge router E_1 to the optical core router C_4. Suppose the route given by the routing processor 305 is E_1-C_1-C_2-C_3-C_4, which could be an existing route used by the flow or a new route.

[0031] To reserve a data channel 205 along the path, the signaling processor 315 at electronic ingress edge

router E_1 first finds an unreserved outbound data channel 205 connecting to the optical core router C_1, say λ_i, from the fiber and channel database 310. It then sends out a Data-Channel-Reservation-Request (DCR-Request) message 705 to optical core router C_1, indicating that outbound data channel λ_i will be reserved for the flow as shown in FIGURE 7. The status of λ_i is changed by the signaling processor 315 from unreserved to reservation in progress in the fiber and channel database 310 as well as in the CIB 350. The DCR-Request message 705 contains the path information and the outbound data channel identifier among others, e.g., (E_1, C_1, C_2, C_3, C_4, λ_i) in this case. The information carried by the DCR-Request message 705 will be stored in the DCP management module 320.

[0032] The signaling processor 515 at optical router C_1 determines that the next hop is optical core router C_2 from the received DCR-Request message 705 sent by electronic edge router E_1. It assigns an unreserved outbound data channel 205, say λ_j, to the burst flow and then sends the modified DCR-Request message 705 - (now with λ_j) to the next optical core router C_2. The status of λ_i and λ_j are changed by the signaling processor 515 from the unreserved state to the reservation in progress state in the fiber and channel database 510 and the status of λ_j is also changed in the corresponding CIB 550 of optical core router C_1. The information carried by the DCR-Request message 705 will be stored in the DCP management module 520. It is assumed here that the error-free transmission of messages between two adjacent signaling processors is guaranteed by the lower layer protocols.

[0033] The same procedure is repeated at optical core routers C_2, C_3 and C_4. Suppose outbound data channel λ_n of optical core router C_3 is chosen for the path (see FIGURE 7). At optical core router C_4, the CIB 550 simply records that inbound channel λ_n is in the status of reservation in progress (set by optical core router C_3) as shown in FIGURE 8, where status "1" means the channels are reserved, "0" means the channels are in the reservation process, and symbol "-" means this optical core router C_4 is a RTN. Optical core router C_4 will send back a DCR-acknowledgement (DCR-ACK) message 710 to optical core router C_3, which in turn goes through optical core routers C_2, C_1, and finally reaches electronic ingress edge router E_1. Upon receiving the DCR-ACK message 710, a router (core 110 or edge 105) in the path will create a new entry in the CIB of the scheduler, specifying that the inbound and outbound data channels 205 are in the reservation process. An example of CIB 550 at optical core router C_1 is shown in FIGURE 9. FIGURE 9 shows a channel information base 550 table. The CIB 550 table shows the name of the DCG_in, G_r. Furthermore, the CIB 550 shows that channel_in has a wavelength of λ_x, channel_out has a wavelength of λ_y, and the status of the data channel 205 is "1", which means the data channel 205 is reserved. The CIB 550 table in FIGURE 9 also shows another DCG_in, G_s. The CIB 550 also shows that channel_in has a wavelength of λ_i, channel_out has a wavelength of λ_j, and the status of the data channel 205 is "0", which means the data channel reservation is in progress. The initial data channel reservation process is now completed.

[0034] If no unreserved outbound data channel 205 is found or a router (core 110 or edge 115) in the path decides not to continue the path setup process, it will send back a negative DCR-acknowledgement (DCR-NAK) message 710 all the way to the electronic ingress edge router E_1. Thus, the attempt by the electronic ingress edge router E_1 to establish a reserved data channel 205 path failed. To insure the error-free transmission and receiving of signaling messages, the signaling processor (both 315 and 515) may be required to send back an acknowledgement (ACK) message to its upstream node when it receives a DCR-Request, DCR-ACK or DCR-NAK. Some time-out mechanism may be used to cope with possible loss of signaling messages.

[0035] Electronic ingress edge router E_1 creates a new queue 1005 after receiving the DCR-ACK 710 from optical core router C_1 as shown in FIGURE 10. This new queue 1005 is used to accommodate the flow bursts to be sent on the reserved data channel λ_i. To reduce or largely eliminate the gaps/voids between bursts sent on the reserved data channel 205, a threshold γ is maintained for the new queue 1005, the value of which could be the traffic volume in bytes or the number of bursts in the new queue 1005. Once the threshold γ is exceeded, the burst flow will be directed to the common queue 1010 until the quantity in the new queue 1005 is dropped below the threshold. A special bit in the burst header packet, called reserved data channel (RC) bit, is used to indicate whether a burst is transmitted on the reserved data channel 205. For bursts sent on the reserved data channel 205, their RC bit is set to 1.

[0036] The actual reservation of the data channels 205 along the optical path is made by the first bursts of the burst flow sent from electronic ingress edge router E_1 on outbound data channel λ_i. For instance, upon receiving the first BHP with RC=1 from data channel λ_i, the scheduler 535 of optical core router C_1 will do the following: (1) reserve the outbound data channel λ_j and configure the optical switching matrix to connect inbound data channel λ_i to outbound data channel λ_j when the first burst is switched; (2) update the status bit in the CIB 550 (see FIGURE 9) from 0 to 1, indicating data channel λ_i and data channel λ_j are now reserved, (3) move data channel λ_j from the unreserved and reservation in progress channel subset to the reserved channel subset in the CIB 550, and (4) change the status of data channel λ_i and data channel λ_j from reservation in progress to reserved in the fiber and channel database 510. At this point, all incoming bursts on data channel λ_i with RC=1 will be switched to outbound data channel λ_j, and no data channel 205 scheduling is need for data channel λ_i. To prevent the potential loss of the first burst

of the flow at an optical core router 110 in the reserved data channel 205 path due to traffic congestion, this burst (with RC=1) may have higher priority in the scheduler 535.

[0037] The same procedure is repeated at optical core routers C_2, C_3, and C_4. So when the first burst with RC=1 reaches optical core router C_4, a reserved data channel path is established (see FIGURE 2), and routers C_1, C_2 and C_3 need not perform any scheduling for the reserved data channels. At optical core router C_4, bursts received on the reserved data channel path will have their RC bits reset to 0 by the scheduler 535 (optical core router C_4 is a RTN). Note that no bandwidth is wasted during the entire data channel reservation process as bursts are still forwarded or switched as before during this period. Note also that BHPs are always forwarded or switched at the switch control unit (SCU) 530 although data channels λ_i and λ_j are cross-connected. A CIB 550 table lookup is required for bursts received from reserved data channels.

[0038] If an electronic ingress edge router 105 decides to terminate the reserved data channel path, either because the average rate of the burst flow is below $R+\Delta$ or for other reasons, it simply sends a burst with an unreserved channel bit RC=0 on outbound data channel λ_i. After receiving one or more bursts with RC=0 on the reserved inbound data channel, an optical core router 110 will terminate the reservation, update the CIB 550 and the fiber and channel database 510 (e.g., removing the entry of data channels λ_i and λ_j in the CIB 550 and moving them to the unreserved channel subset, if the optical core router is C_1), and resume the normal forwarding and/or switching for new arriving bursts. The optical core router 110 will also send a confirmation message back to electronic' edge router E_1. Again, no bandwidth is wasted during the reservation termination process.

[0039] To prevent malfunctions in the electronic ingress edge routers 105 or optical core routers 110, a timer (not shown) is maintained in each router (105, 110 or 115) along the path, which should be reset by a refresh message sent by the electronic ingress edge router 105 before it expires. If the timer expires, the corresponding router will terminate the channel reservation and inform others routers.

[0040] In general, if the average bit rate of the flow is $m \cdot R+\Delta(m)$ where m is a nonnegative integer, up to m data channel 205 paths could be reserved. These data channel 205 paths may follow the same route or different routes, but have the same RTN. The number of channels in a data channel 205 path could be more than one. The threshold $\gamma(m)$ now is a function of m. The above data channel reservation method is also valid if an electronic ingress edge router 105 has more than one RTN.

[0041] The data channel reservation method of the present invention is flow-driven, initiated by ingress edge router on demand, protocol independent, and adaptive to the average bit rate of a flow of bursts. The data channel reservation method of the present invention is also suitable for both loose and strict definitions of burst flows. A burst flow is loosely defined as a set of bursts which have the same electronic ingress edge router 105, follow the same path, and are destined to the same reservation termination node (RTN). The strict definition of a burst flow requires that the bursts have the same or similar attributes like quality of service (QOS). The data channel reservation method can also be combined with a layer 2 protocol like MPLS to establish a label switched path (LSP) with bandwidth reservation. Note that the above data channel reservation approach is also suitable for establishing a path with certain reserved bandwidth (of data channels 205) in the optical burst-switched network 100 even if the flow driven factor is not considered.

[0042] In summary, the present invention provides a system and method for reserving data channels in an optical burst-switched network. A data channel (or a multiple of data channels) along an optical path in an optical burst-switched network is reserved by first transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node. Next, the data channel reservation request is processed at all nodes along the path. A data channel reservation acknowledgement is then transmitted from the reservation termination node to the electronic ingress edge router. Finally, the data channel path is reserved once an initial burst(s) which contains a reserve data channel bit reaches the reservation termination node.

[0043] Although the present invention has been described in detail, it should be understood that various changes, substitutions and alterations can be made hereto without departing from the spirit and scope of the invention as described by the appended claims.

Claims

1. A method for reserving a data channel along an optical path in an optical burst-switched network, comprising the steps of:

   transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node;
   processing said data channel reservation request at said reservation termination node;
   transmitting a data channel reservation acknowledgement from said reservation termination node to said electronic ingress edge router; and
   reserving said data channel once an initial burst comprising a reserve data channel bit reaches said reservation termination node.

2. The method of Claim 1, further comprising the steps of:

   monitoring a burst flow bit rate;
   locating an unreserved data channel between said electronic ingress edge router and said reservation termination node when said flow of bursts exceeds a threshold bit rate;
   creating a new queue in said electronic ingress edge router for accommodating said flow of bursts to be transmitted on said data channel; and
   returning a negative data channel request acknowledgement from a core router or said reservation termination node along said optical path to said ingress edge router if there is no said unreserved data channel available between said core router and said reservation termination node.

3. The method of Claim 1, wherein a plurality of data channels are reserved along said optical path in said optical burst-switched network.

4. The method of Claim 1, wherein said reservation termination node can either be an egress edge router or an optical core router.

5. The method of Claim 4, wherein said data channel reservation request is transmitted from said optical core router to said reservation termination node.

6. The method of Claim 4, wherein a plurality of said optical core routers can be between said electronic ingress edge router and said reservation termination node.

7. The method of Claim 6, wherein said data channel reservation request is processed at each optical core router between said electronic ingress edge router and said reservation termination node.

8. The method of Claim 4, wherein said electronic edge router comprises:

   a plurality of input/output ports;
   a first routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
   a first signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
   a first fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
   a first data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
   a burst flow monitoring module operable to monitor the burst flow between said electronic ingress edge router and said reservation termination node and inform said signaling processor when the burst flow rate exceeds or drops below a given threshold;
   a first scheduler operable to schedule the transmission of bursts on data channel groups and their associated burst header packets on control channel groups;
   a first routing information base for storing all necessary optical burst-switched network routing information for said optical burst-switched network; and
   a first forwarding information base for storing next hop information for arriving bursts.

9. The method of Claim 8, wherein said next hop can either be said electronic egress edge router or said optical core router.

10. The method of Claim 8, further comprising the step of updating said first routing information base and first forwarding information base in said electronic edge router with information on changes in network status received at said electronic edge router.

11. The method of Claim 8, wherein said network information stored in said first fiber and channel database includes inbound and outbound fibers, wavelengths within each said inbound and outbound fibers, inbound and outbound data and control channel groups, channels within each said data and channel control groups, mapping of said data and control channel groups, said channels to said fibers and wavelengths, and the status of each said inbound and said outbound data channel.

12. The method of Claim 11, wherein said first scheduler comprises a first channel information base, said first channel information base operable to store a subset of said information stored in said first fiber and channel data base.

13. The method of claim 1, wherein said optical core router comprises:

   a plurality of input/output ports;
   a second routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
   a second signaling processor operable to transmit and receive optical burst-switched network

information from neighboring communication devices through said input/output ports;
a second fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a second data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a second routing information base for storing all necessary routing information for said optical burst-switched network; and
a switch control unit operable to configure an optical switching matrix to switch said bursts through said optical burst switched network.

14. The method of Claim 13, wherein said switch control unit comprises:

a second scheduler operable to schedule the transmission of bursts and their associated burst header packets on data and control channel groups, respectively;
a second forwarding information base for storing next hop information for arriving bursts; and
a first label information base for storing label-swapping information.

15. The method of Claim 14, wherein said second scheduler comprises a second channel information base, said second channel information base operable to store a subset of said information stored in said second fiber and channel data base.

16. The method of Claim 2, wherein said unreserved data channel can be located either by default route or by explicit route.

17. The method of Claim 1, wherein said data channel can be in one of three possible states including an unreserved state, a reservation in progress state, or a reserved state.

18. A method for terminating a reserved data channel in an optical burst-switched network, comprising the steps of:

transmitting a burst with a burst header packet comprising an unreserved data channel bit from an electronic ingress edge router to a reservation termination node along a reserved data channel path;
processing said unreserved data channel bit at said reservation termination node;
transmitting a confirmation message from said reservation termination node to said electronic ingress edge router confirming that the reservation of said reserved data channel is terminated.

19. The method of Claim 18, wherein said reservation termination node can either be an egress edge router or an optical core router.

20. The method of Claim 18, wherein said burst with a burst header packet comprising an unreserved data channel bit is transmitted from said optical core router to said reservation termination node.

21. The method of Claim 18, wherein a plurality of said optical core routers are between said electronic ingress edge router and said reservation termination node.

22. The method of Claim 21, wherein said data channel reservation request is processed at each optical core router between said electronic ingress edge router and said reservation termination node.

23. The method of Claim 19, wherein said electronic ingress edge router and said electronic egress edge router both comprise:

a plurality of input/output ports;
a first routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a first data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a burst flow monitoring module operable to monitor the burst flow between said electronic ingress edge router and said reservation termination node and inform said signaling processor when the burst flow rate exceeds or drops below a given threshold;
a first scheduler operable to schedule the transmission of bursts on data channel groups and their associated burst header packets on control channel groups;
a first routing information base for storing all necessary optical burst-switched network routing information for said optical burst-switched network;
a first forwarding information base for storing

next hop information for arriving bursts.

24. The method of Claim 23, wherein said first scheduler comprises a first channel information base.

25. The method of claim 19, wherein said optical core router comprises:

a plurality of input/output ports;
a second routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a second data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a second routing information base for storing all necessary routing information for said optical burst-switched network; and
a switch control unit operable to configure an optical switching matrix to switch said bursts through said optical burst switched network.

26. The method of Claim 25, wherein said switch control unit comprises:

a second scheduler operable to schedule the transmission of bursts on data control groups and burst header packets on control channel groups;
a second forwarding information base for storing next hop information for arriving bursts; and
a first label information base for storing label-swapping information.

27. The method of Claim 26, wherein said second scheduler comprises a second channel information base.

28. A system for reserving a data channel along an optical path in an optical burst-switched network, comprising:

an electronic ingress edge router operable to transmit a data channel reservation request; and
a reservation termination node operable to receive and process said data channel reservation request, transmit a data channel reservation acknowledgement back to said electronic ingress edge router, and receive an initial burst comprising a reserve data channel bit completing the reservation processes.

29. The system of Claim 28, where a plurality of data channels are reserved along said optical path in said optical burst-switched network.

30. The system of Claim 28, wherein said reservation termination node can either be an egress edge router or an optical core router.

31. The system of Claim 30, wherein said data channel reservation request is transmitted from said optical core router to said reservation termination node.

32. The system of Claim 30, wherein a plurality of said optical core routers can be between said electronic ingress edge router and said reservation termination node.

33. The system of Claim 30, wherein said electronic edge router comprises:

a plurality of input/output ports;
a first routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a first data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a burst flow monitoring module operable to monitor the burst flow between said electronic ingress edge router and said reservation termination node and inform said signaling processor when the burst flow rate exceeds or drops below a given threshold;
a first scheduler operable to schedule the transmission of bursts on data channel groups and their associated burst header packets on control channel groups;
a first routing information base for storing all necessary optical burst-switched network routing information for said optical burst-switched network; and
a first forwarding information base for storing next hop information for arriving bursts.

34. The system of Claim 33, wherein said next hop can either be said electronic egress edge router or said optical core router.

35. The system of Claim 33, wherein said first routing information base and first forwarding information base in said electronic edge router are updated with information on changes in network status received at said electronic edge router.

36. The system of Claim 33, wherein said network information stored in said first fiber and channel database includes inbound and outbound fibers, wavelengths within each said inbound and outbound fibers, inbound and outbound data and control channel groups, channels within each said data and channel control groups, mapping of said data and channel control groups, said channels to said fibers and wavelengths, and status of each said inbound and said outbound data channel.

37. The system of Claim 36, wherein said first scheduler comprises a first channel information base, said first channel information base operable to store a subset of said information stored in said first fiber and channel data base.

38. The system of claim 29, wherein said optical core router comprises:

a plurality of input/output ports;
a second routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a second data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a second routing information base for storing all necessary routing information for said optical burst-switched network; and
a switch control unit operable to configure an optical switching matrix to switch said bursts through said optical burst switched network.

39. The system of Claim 38, wherein said switch control unit comprises:

a second scheduler operable to schedule the transmission of bursts and their associated burst header packets on data and control channel groups, respectively;
a second forwarding information base for storing next hop information for arriving bursts; and
a first label information base for storing label-swapping information.

40. The system of Claim 39, wherein said second scheduler comprises a second channel information base, said second channel information base operable to store a subset of said information stored in said second fiber and channel data base.

41. The system of Claim 28, wherein said data channel can be in one of three possible states, including an unreserved state, a reservation in progress state, or a reserved state.

42. A system for terminating a reserved data channel in an optical burst-switched network, comprising:

an electronic ingress edge router operable to transmit a burst comprising an unreserved data channel bit from said electronic ingress edge router to a reservation termination node; and
a reservation termination node operable to receive said burst comprising said unreserved data channel bit, process said unreserved data channel bit, and transmit a confirmation message to said electronic ingress edge router confirming that said reservation of said reserved data channel is terminated.

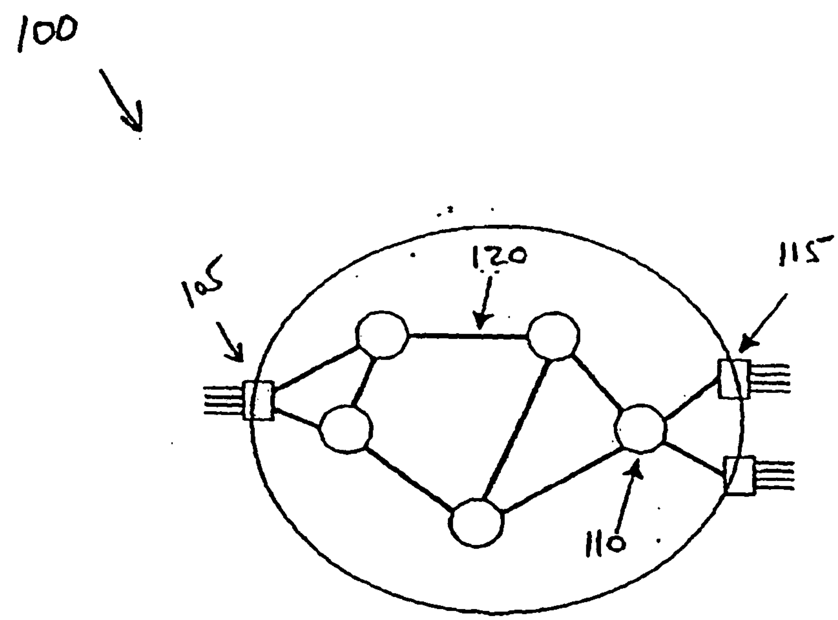

Figure 1: An optical burst-switched network.

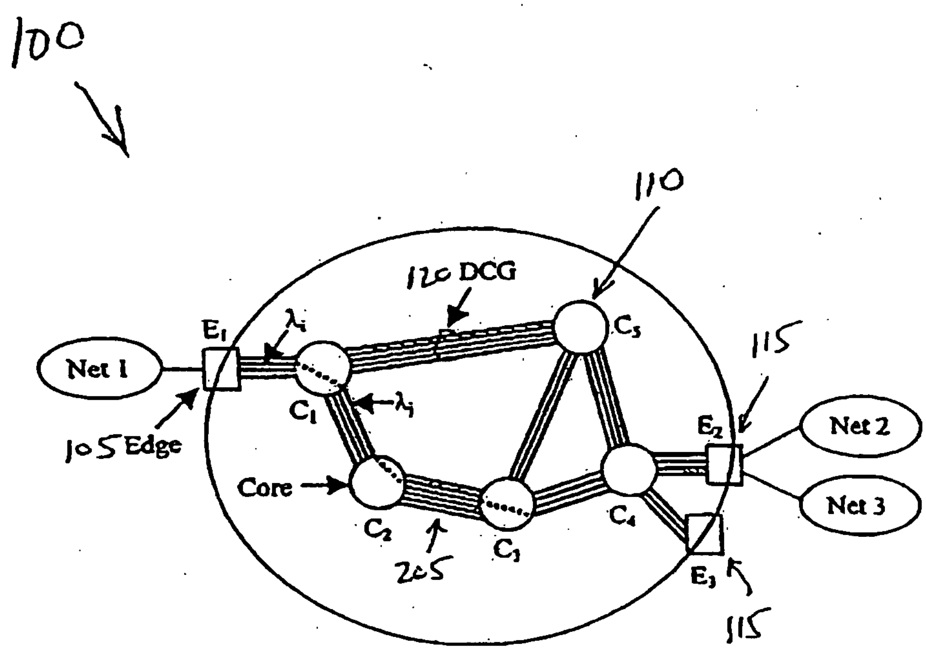

Figure 2: An optical burst-switched network.

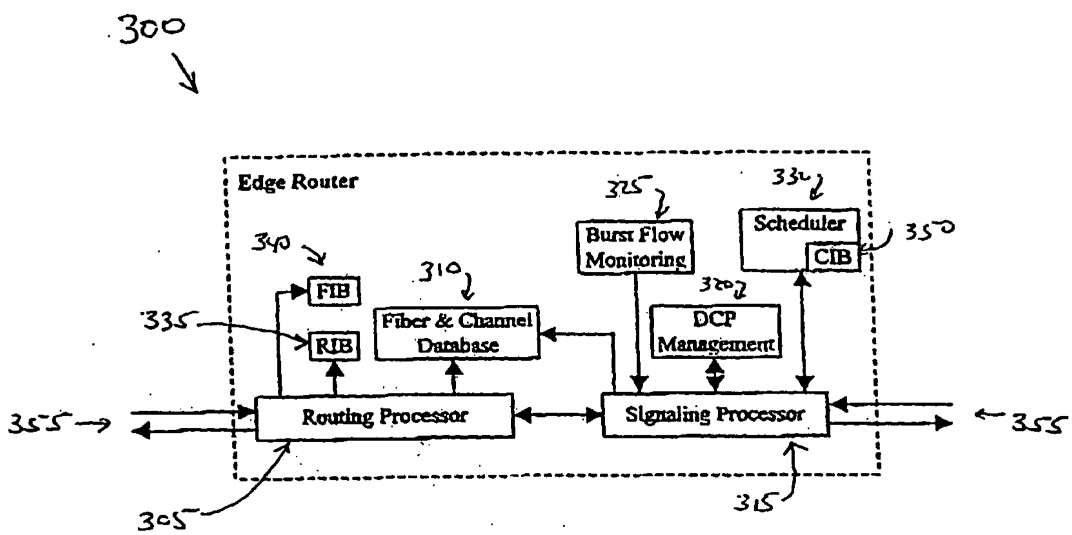

Figure 3: Relevant function blocks at an edge router.

400

IP address	DCG_out	Label_out
A_1	G_a	L_x
A_2	G_b	L_y

Figure 4: Sample forwarding information base (FIB) at an edge router.

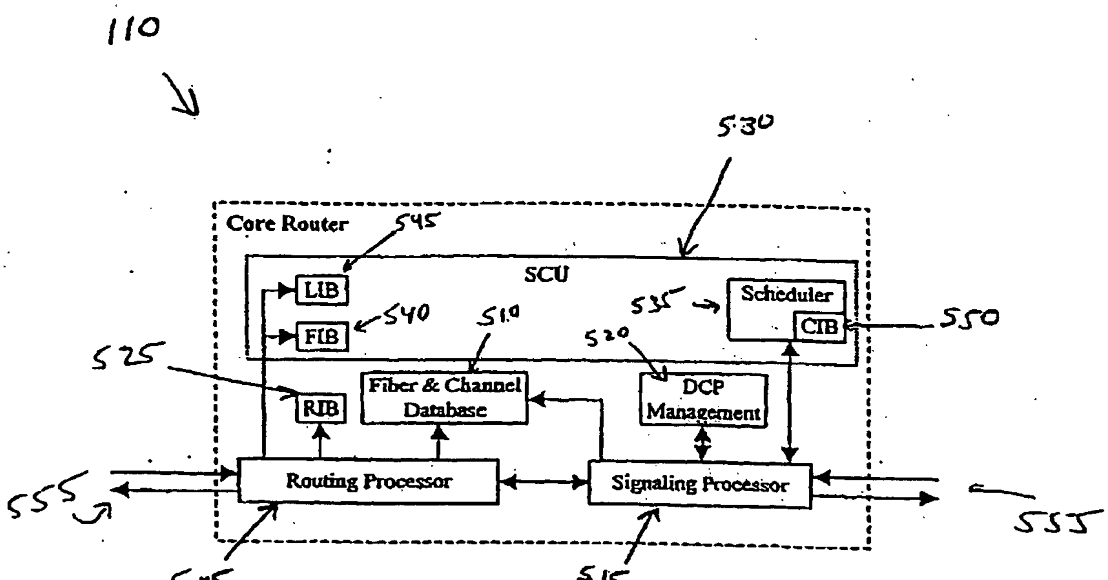

Figure 5. Relevant function blocks at a core router.

600

DCG_in	Label_in	DCG_out	Label_out
G_a	L_b	G_c	L_d
G_e	L_f	G_g	L_h

Figure 6 : Sample label information base (LIB) at a core router.

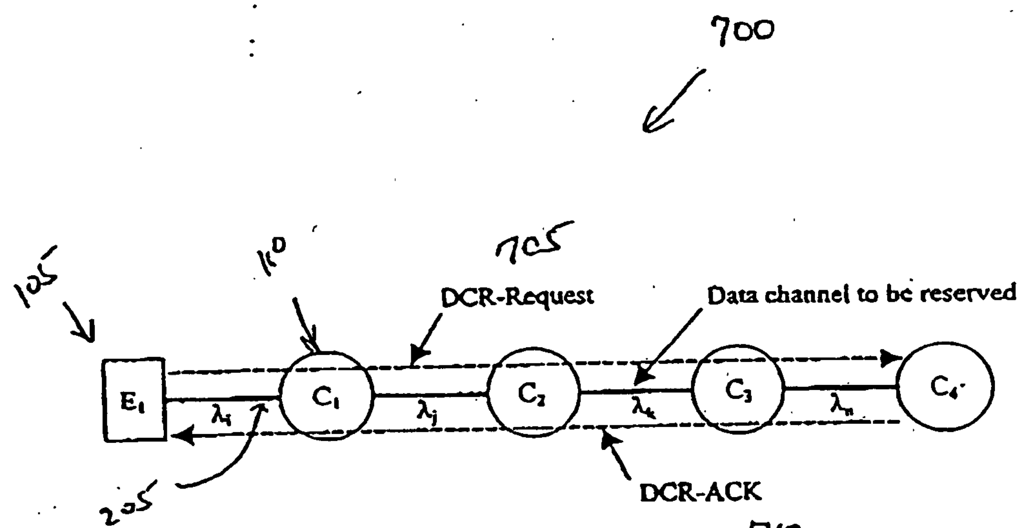

Figure 7 Data channel path setup.

800

DCG_in	Channel_in	Channel_out	Status
G_p	λ_w	λ_v	1
G_q	λ_n	-	0

Figure 8 Sample channel information base (CIB) at core router C_4.

900

DCG_in	Channel_in	Channel_out	Status
G_r	λ_x	λ_y	1
G_t	λ_r	λ_y	0

Figure 9 Sample channel information base (CIB) at core router C_1.

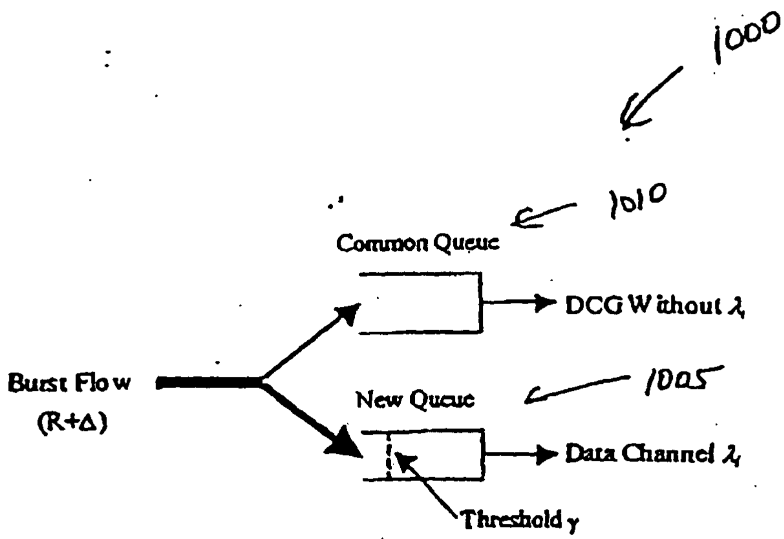

Figure 10. A new queue with some threshold for the reserved data channel.